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- NOBLE GASES

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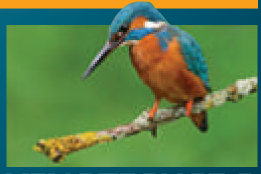

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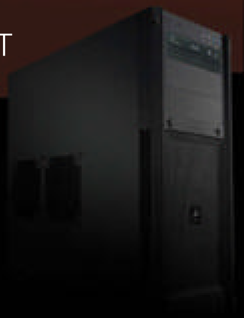

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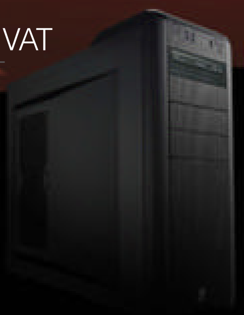

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HOW IT WORKS

ISSUE 43

# WELCOME

The magazine that feeds minds!

## Get in touch

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# FEED YOUR MIND

The point is jets are cool. These air-breathing combustion engines deliver the immense mechanical power to propel the world's most extreme machines at staggering speeds. From the smell of jet fuel in the air to the screaming sound of an afterburner and the crack of a sonic boom, everything to do with the jet engine epitomises macho, high-octane thrills.

This issue we reveal the ins and outs – literally – of the most incredible jet engines in the world. Turn to page 12 where we'll be exploring the mindblowing anatomy of such world-class examples as the Rolls-Royce 1000-TEN on board Boeing's 787 Dreamliner and the F135 installed on the F-35 Lightning II fighter plane. Just how does each of the different jet engine types work and what enables them to achieve such blistering speeds?

Also in the issue, we asked our followers on Twitter to send in any amazing science facts for us to explain in the magazine. Our inbox went wild and we were stunned at the sheer multitude of cool trivia you shared. For accessible explanations of your top 50 most incredible science facts, head to page 36 and prepare to be amazed.

Enjoy the issue.

Helen

**Helen Laidlaw**
Editor

## Meet the team...

**Robert**
**Features Editor**
Sitting down with Sir David Attenborough – surely the most authoritative naturalist on Earth – was an honour.

**Ben**
**Features Editor**
If it weren't for tight traffic controls and state-of-the-art CCTV tech, London's roads would be in total disarray.

**Helen**
**Senior Art Editor**
I can't begin to imagine the courage it must take for an astronaut to complete a spacewalk – incredible.

**Adam**
**Senior Sub Editor**
There's something awe-inspiring about a huge swarm of animals, but can the 'hive mind' really exist?

## The sections

The huge amount of info in each issue of How It Works is organised into these sections:

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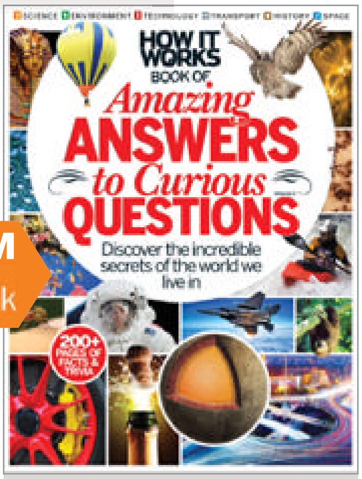
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The magazine that feeds minds!

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Find out more about the writers in this month's edition of How It Works…

### Alexandra Cheung
**50 amazing science facts**

Former employee of CERN and the Science Museum, Alex took up the challenge of answering your many curious questions on our favourite subject – science – this issue. Check them out on page 36.

### Luis Villazon
**Swarms**

Luis has a passion for all creatures – great and small – and what better excuse to examine both types en masse than to write a feature about the critters that live as part of a swarm in order to survive?

### Vivienne Raper
**Underwater volcanic vents**

With her PhD in Geophysics, earth science is one of Vivienne's favourite subjects. This issue she explains the ins and outs of deep-sea geothermal vents that resemble geysers up on land.

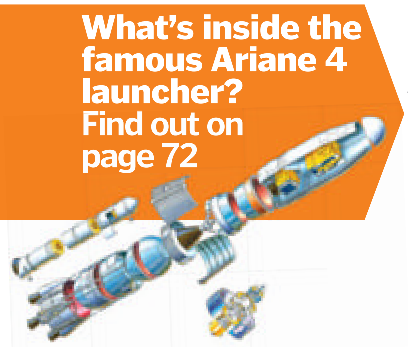
### Ella Carter
**Estuaries**

New to the ranks of How It Works' esteemed writers, oceanography expert Ella dived straight into her first feature for us by revealing the makeup of estuaries and the diverse life they support.

### Dave Roos
**Jet power**

This issue Dave is set to thrill you all with his feature that explores the mindblowing power of the jet engine. He looks at everything from turbofans to scramjets and the origins of this key invention.

What's inside the famous Ariane 4 launcher? Find out on page 72



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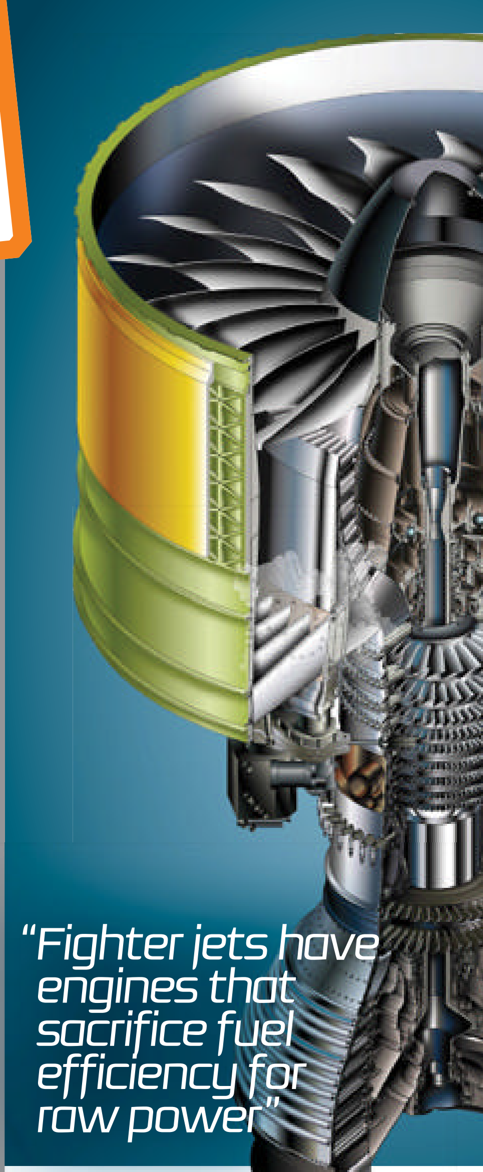

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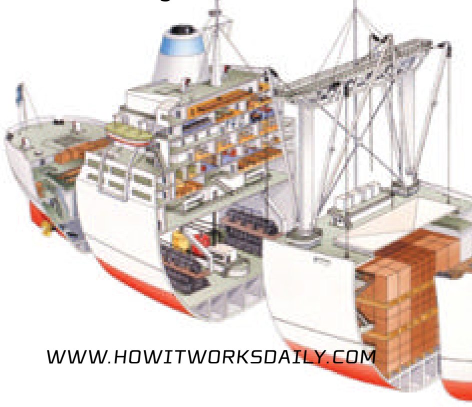

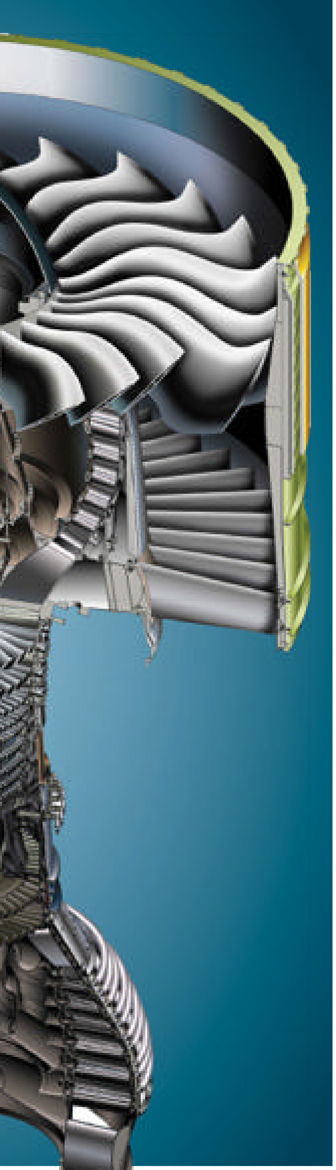

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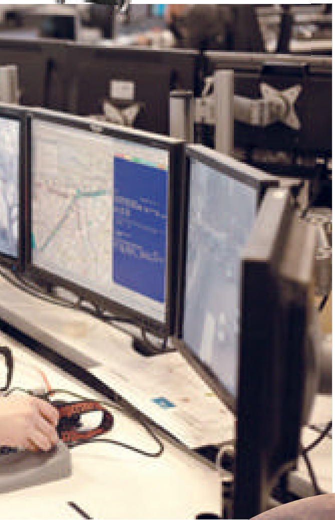

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# GLOBAL EYE NEWS

Showcasing the incredible
world we live in...

The new quantum radar could lead to many stealth aircraft – such as the B-2 Spirit – to become obsolete

# New radar sees stealth planes

## A revolutionary unjammable radar has been developed that uses the signature of photons to expose previously near-invisible aircraft

A team of scientists at the University of Rochester, New York State, have developed a brand-new radar system that employs the quantum properties of photons to create an unjammable radar signal.

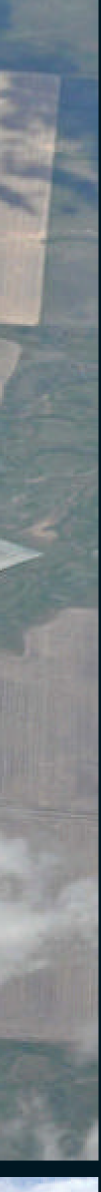
Unlike conventional radar systems, which can be compromised by the hi-tech blocking systems now installed on the majority of modern stealth planes, the quantum radar can't be fooled. It will detect any indication that the signal is being meddled with.

The new device works on the principle that any jamming system must modify the radar's polarised photon signal at a quantum level in order to generate a false image, with that alteration identifiable by sensors.

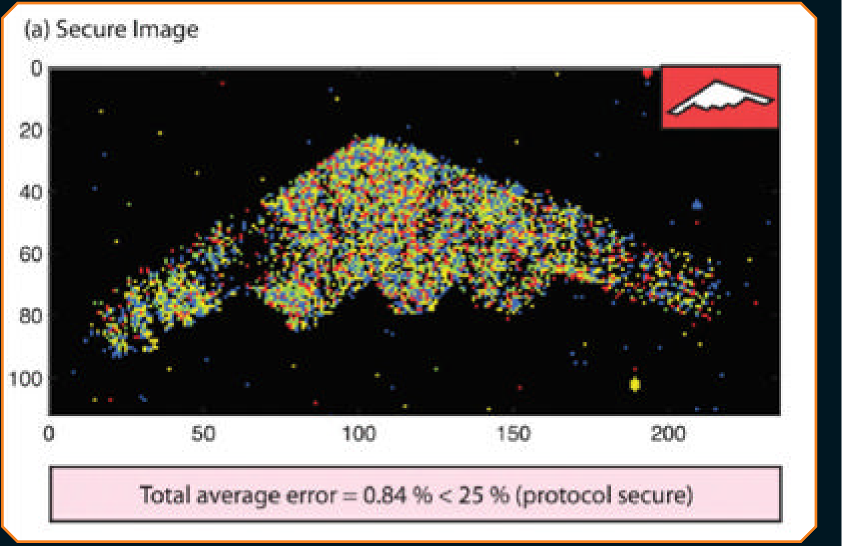
This process was tested by the research team's leader, Mehul Malik, at the University of Rochester's Institute of Optics, where he fired the quantum radar at a stealth bomber-shaped target and measured the returning photons' polarisation error rate.

Incredibly, when a false signal was being projected by the target, the error rate jumped to over 50 per cent from the 0.84 per cent error rate received when no jamming was used.

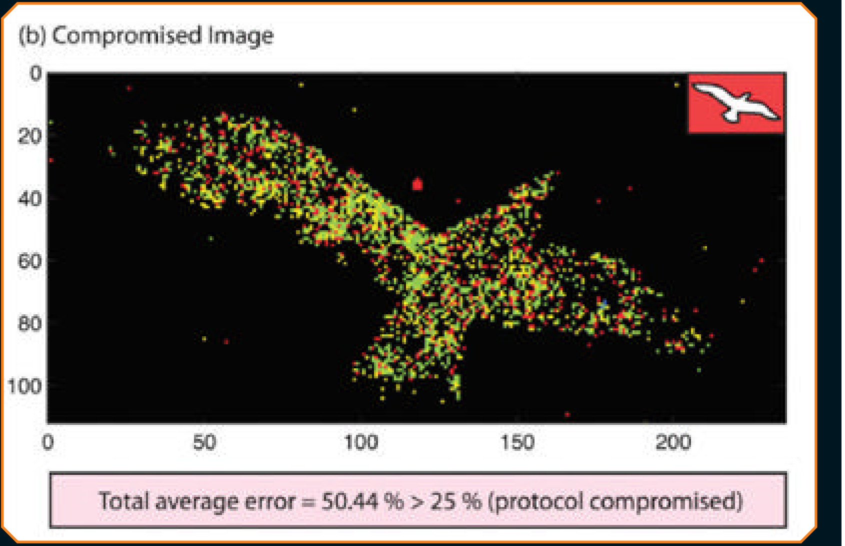
Speaking on the publication of the findings, a spokesperson from Massachusetts Institute of Technology's Tech Review's Physics blog said: "[The quantum radar is] an impressive demonstration of the first imaging system that is unjammable thanks to quantum mechanics." While the team are buoyed by the results, they admit there's room for improving the system, with the study highlighting the possibility of a sophisticated jammer being developed that is able to use quantum teleportation to replace the radar signal's photons with duplicates carrying false data.



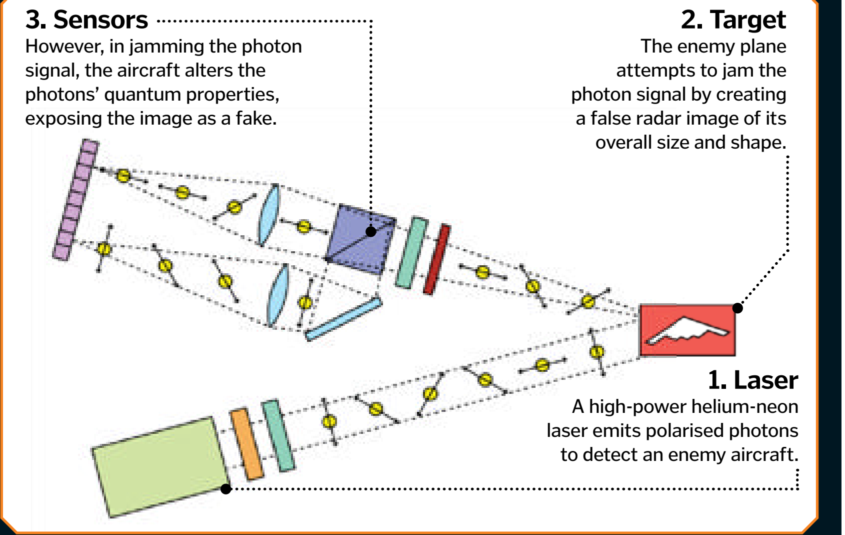
> "Unlike conventional radar systems, which can be compromised, the quantum radar can't be fooled"



If the target aircraft is incapable of jamming the quantum radar's signal, then a true image of it is received by the radar's sensors, with its validity confirmed by the very low number of statistical errors (ie less than one per cent) in the photons' quantum properties



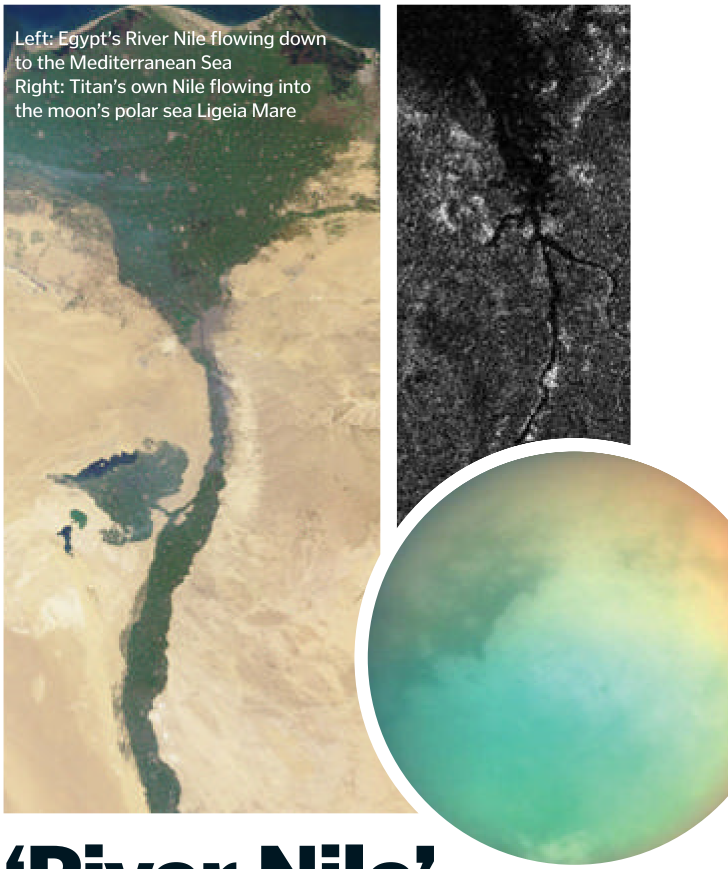
On the other hand, if the target aircraft generates a jamming signal to disguise its appearance as shown here, the quantum radar receives the false image but can detect the statistical errors in the photons' quantum properties, revealing it to be a forgery



**3. Sensors**
However, in jamming the photon signal, the aircraft alters the photons' quantum properties, exposing the image as a fake.

**2. Target**
The enemy plane attempts to jam the photon signal by creating a false radar image of its overall size and shape.

**1. Laser**
A high-power helium-neon laser emits polarised photons to detect an enemy aircraft.



Left: Egypt's River Nile flowing down to the Mediterranean Sea
Right: Titan's own Nile flowing into the moon's polar sea Ligeia Mare

# 'River Nile' found on Titan

## The Cassini space probe has discovered an ethane river on a Saturnian moon that has been twinned with the African Nile

A 400-kilometre (250-mile)-long river of liquid ethane has been uncovered on Saturn's largest moon, Titan. The discovery, which was made by the Cassini space probe, confirms what scientists had long thought to be true: that Titan has an incredibly active and stable system of surface liquids that express themselves in rivers, streams, lakes and even seas.

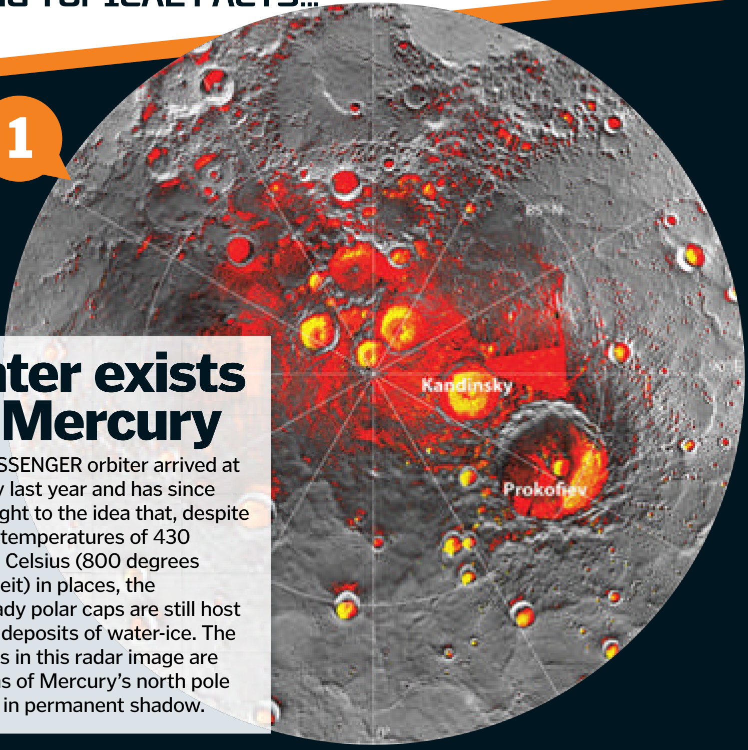
Indeed, the scale and complexity of the river has seen it dubbed the 'River Nile of Titan', with it and the Egyptian waterway on Earth resembling each other in satellite imagery. As with the terrestrial Nile, Titan's counterpart begins in highlands, runs down a large valley and then empties into a vast sea, called the Ligeia Mare – which is one of three that cover the moon's northern latitudes.

Speaking on the imaging of Titan's Nile, Cassini project scientist Nicolas Altobelli said: "This radar-imaged river by Cassini provides another fantastic snapshot of a world in motion, which was first hinted at from the images of channels and gullies seen by the ESA's Huygens probe as it descended to the moon's surface in 2005."

© NASA; University of Rochester/Malik et al

# 10 COOL THINGS WE LEARNED THIS MONTH

AMAZING TOPICAL FACTS…



## 1

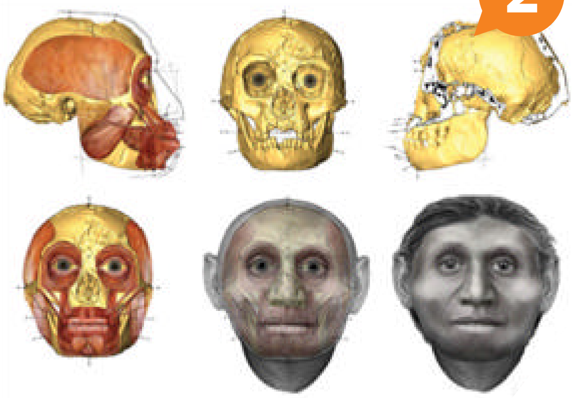
## Water exists on Mercury

The MESSENGER orbiter arrived at Mercury last year and has since lent weight to the idea that, despite surface temperatures of 430 degrees Celsius (800 degrees Fahrenheit) in places, the ever-shady polar caps are still host to large deposits of water-ice. The red parts in this radar image are the areas of Mercury's north pole that are in permanent shadow.

## 2

## Real 'hobbit' face reconstructed

Scientists at the University of Wollongong, NSW, Australia, have revealed the face of a real-world 'hobbit'. The female Homo floresiensis skull was discovered by Mike Morwood, Thomas Sutikna and a team of Indonesian and Australian archaeologists in 2003 on the island of Flores and has been reconstructed by Dr Susan Hayes. Homo floresiensis was a bipedal species in the same genus as modern man, but it stood only around 0.9 metres (three feet) tall and had a relatively small brain.



© Dr Susan Hayes, University of Wollongong

## 3

## Wood could replace bones

Rattan wood is commonly used to make furniture, but scientists think its similar microscopic structure means it could also be used for bone transplants, replacing other artificial options like metal. The process would involve treating the rattan to remove plant substances like lignin and cellulose, leaving behind a carbon 'skeleton' with a very similar makeup to bone.

© Mobler Rattan

## 4

## Insects can masquerade as plants

Deception is a common strategy of predators in the natural world and especially in the insect kingdom. The orchid mantis is native to Malaysia and found on flowering plants like papaya trees, where it uses its colourful, flower-shaped body to lure bees, butterflies, fruit flies and even small lizards in for the kill.

## 5

## Maori cooking reveals Earth's magnetic past

Scientists keen to map Earth's magnetic history in the southern hemisphere have turned to old Maori cooking pits, or hangi, for help. The stones found at these sites were demagnetised by temperatures as high as 1,100 degrees Celsius (2,012 degrees Fahrenheit), then magnetised again in the direction of the prevalent field at the time, creating a reliable record of the planet's magnetism as far back as the 13th century.

## 6

## Andromeda and our galaxy set to collide

Our own Milky Way and 'nearby' galaxy Andromeda, 2.5 million light years away, are on a head-on collision course. Using data from Hubble telescope measurements, supercomputers have determined that the two galaxies are destined to crash and merge, throwing our Solar System into a completely different part of the new galaxy and changing our night sky. This won't happen for another 4 billion or so years though.

7

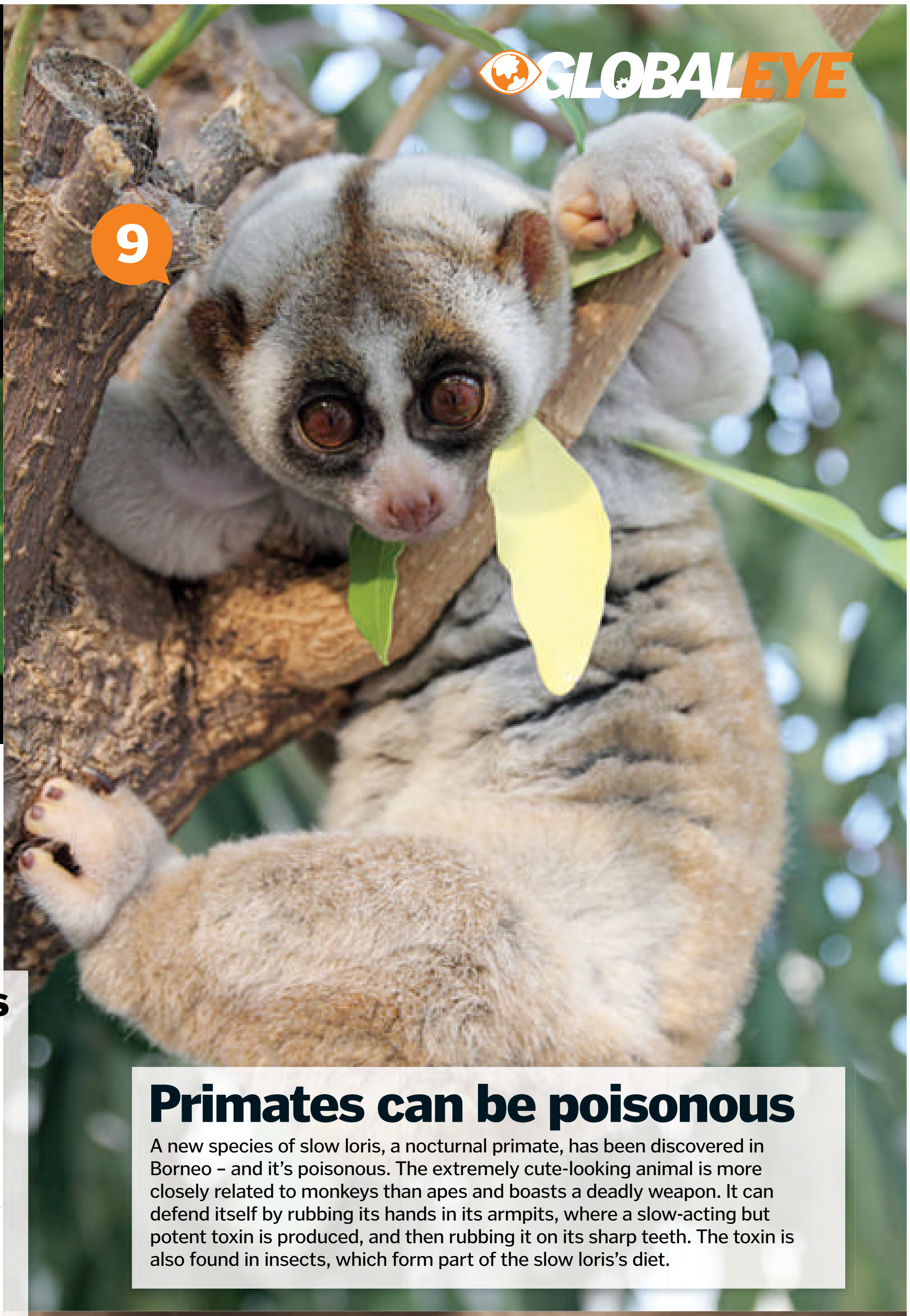
## The pharaohs weren't immortal

Far from it, in fact, as Egyptologists have solved a murder mystery surrounding Ramesses III, whose throat was cut 3,000 years ago. One of his wives, in collusion with the high priest, murdered the pharaoh and his first son in order to make her own son first in line for the throne.

8

## Cheese is extra mature

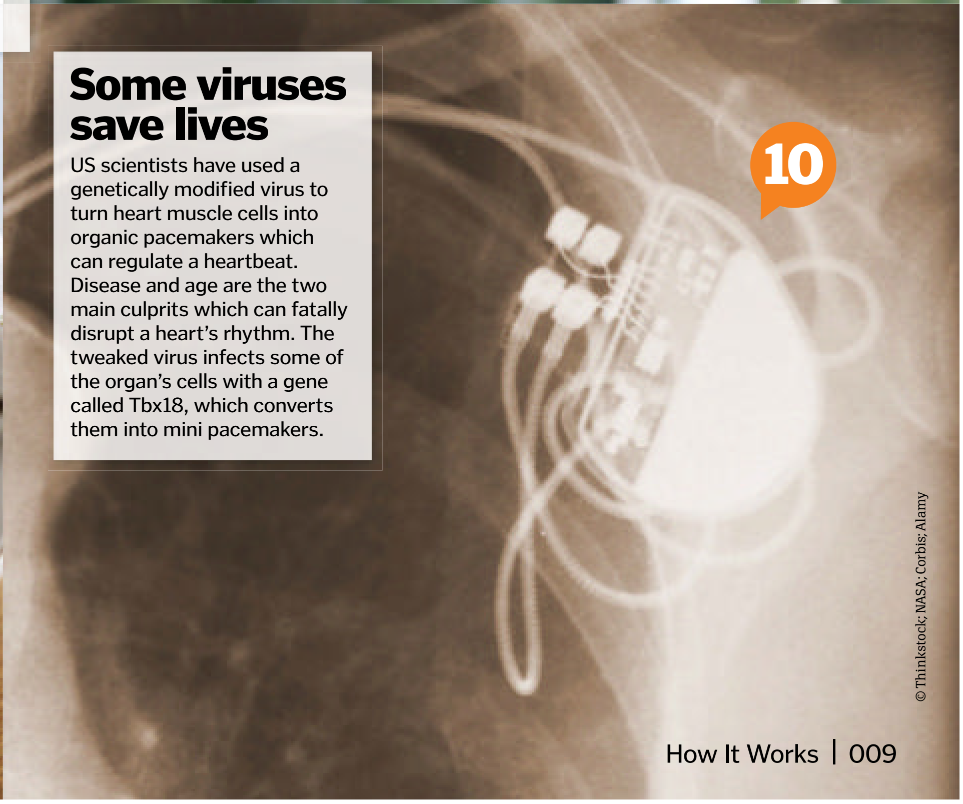
Archaeologists in Poland have uncovered fragments of pottery from Neolithic times that was used to strain cheese. The 7,500-year-old pottery originally had holes in the bottom to strain liquid out and milk residues were detected on the fragments.



9

## Primates can be poisonous

A new species of slow loris, a nocturnal primate, has been discovered in Borneo – and it's poisonous. The extremely cute-looking animal is more closely related to monkeys than apes and boasts a deadly weapon. It can defend itself by rubbing its hands in its armpits, where a slow-acting but potent toxin is produced, and then rubbing it on its sharp teeth. The toxin is also found in insects, which form part of the slow loris's diet.



10

## Some viruses save lives

US scientists have used a genetically modified virus to turn heart muscle cells into organic pacemakers which can regulate a heartbeat. Disease and age are the two main culprits which can fatally disrupt a heart's rhythm. The tweaked virus infects some of the organ's cells with a gene called Tbx18, which converts them into mini pacemakers.

© Thinkstock; NASA; Corbis; Alamy

# Sir David Attenborough

## In his 60th year of broadcasting, Britain's most famous naturalist talks to How It Works about his latest show and a lifelong career working with animals

**How It Works: In your new show *Natural Curiosities* you look at just ten animals across five episodes. How did you decide which creatures to focus on?**

**David Attenborough:** When you come to think about it the editorial attitude you take to natural history on television is quite limited. I mean, there's the adventure story, in which the amount of time you see animals is minimal. A [presenter] will say, "Here we are and if I keep walking maybe I'll catch up with the animal in question, do a bit of exploring to find it, take a snapshot of it and say, 'Hooray'." Well, that is in a sense an adventure and it is none-the-worse for it. Then there's the big sledgehammer series where you use all the visual apparatus you can think of to get mindblowing images, such as in *Frozen Planet*, and that's fine too. And then there's the conservation angle, where it is very much looking at what is being done to protect environments and animals. But there are other ways of doing it and there are other things about animals that are not included in those aforementioned types. One of them is the history of how human beings came to an understanding about an animal, the myths surrounding them, putting them into a historical context – how they were discovered, what we have learned about them and how they have evolved. This is the approach we have taken with *Natural Curiosities* and it's very exciting, as it's a brand-new [format].

**HIW: You deal with a lot of myths in the series – what role has folklore played in shaping these animals' identities?**

**DA:** I think you have to allow for the fact that the human imagination will elaborate and fill gaps, as it were, and will invent an animal like a dragon that breathes fire whether or not there is one. You're quite at liberty to, as no one can prove conclusively whether you're right or wrong. I mean, the Komodo dragon is one example – it has nothing to do with dragon legend, because no one knew it was there, and it was only post-hoc that someone gave it that name. But equally there's an episode in the series that deals with narwhals and how they were said to have unicorn horns. In it we describe how [English explorer] Martin Frobisher comes back from the Arctic and says to Queen Elizabeth I, "I've got a unicorn's horn! It'll only cost you a million quid." That sort of offbeat aspect of natural history has not been addressed anywhere else before.

**HIW: Do you feel discussing animals in a more human context makes it easier for the audience to connect with them?**

**DA:** I think so. If you look at myths it tells you a lot about the human mind, which is very interesting, as well as the animals themselves. But it's just like reading a story; you don't always have to have biographies that are true, or indeed just fairy stories that are [made up]. There are lots of different ways of looking at these things and all of them should have a place because they are fun, interesting and allow the imagination [free rein]. It would be a great pity if the only shows we ever made were things produced as a scientific statement.

**HIW: Do you feel scandals around certain species – such as the duck-billed platypus – have affected how we perceive them as well as how they are studied?**

**DA:** The story of the discovery of many creatures – in which London's Natural History Museum has played a crucial part – is a riveting one. But it tells you more about naturalists than it does about the animals. The study of history itself is a fascinating subject and the discovery of dinosaurs, or ammonites, or the platypus is just as interesting in a different aspect of our story. The platypus represents a stage between reptiles and mammals – and birds come to that – which is a transitional phase. And in evolutionary terms transitional phases don't last long. What happens is you get a transitional form that exploits some new faculty or another, but once it's fully developed that creature will become much more efficient. As a result the [in between] phase [can't compete] and becomes extinct. This is why these links between the great groups are so rare. So there has to be a particular specialism to enable a certain transitional form to survive and the duck-billed platypus can boast one of those: it is a highly specialised feeder. The thing on its head that looks like a beak is in fact a radar probe that it uses to detect little crustaceans. It's a mammal and the bill has nothing to do with birds, but it also retains a lot of reptilian characteristics, eg it's one of just two living mammals to lay eggs.

> "Why are nature programmes so popular on TV? Because they are beautiful, they are unexpected, they are true"

**HIW: What was it like revisiting certain species on film after so many years?**

**DA:** Well, I didn't choose that footage – that was done by the show's producers, who looked back through the BBC archive and said, "Oh, we ought to show that" and I said, "Are you sure? Me eating turtle eggs!" I think they were right to include it in the end though as it shows how the world has changed. Of course we were the first generation who could do that – where you could hear yourself speaking after you have spoken, and what a funny thing it is too. The way your accent changes is incredible.

**HIW: Which is the most extraordinary animal that you've ever encountered?**

**DA:** What's the most extraordinary animal I've ever encountered? I really don't know. I mean, there are so many absolutely astounding things and the more you know about them the more astounding they get. So I don't think I could possibly say a particular one… I don't know how I'd even start.

**HIW: Did you learn anything new during *Natural Curiosities* that made you view the species in a different light?**

**DA:** Mostly I have to say that it was the historical background to many of the species. For example, I didn't know that Lord Clive of India was very fond of zebras. So much so that he had a pair and he thought it would be nice if he could tame them. He thought that one way to tame them would be to take a male zebra and get it to breed with a female donkey in the hope that the offspring might be more malleable. So, he introduced his zebra to a female donkey that had been painted with black stripes, and the male zebra reportedly went, 'Wow!' and they produced a foal. Whether or not the offspring was domesticated, we don't know.

**HIW: Do you feel quirkier stories are better at engaging younger viewers?**
**DA:** I think unusual stories are as engaging as any other. But, you know, young people are just fascinated by animals – they don't need spoon-feeding. You show young people animals and they are [instinctively drawn to] them, and rightly so. I think everybody of any age is interested in animals. As children grow up they get attracted by iPhones and computer games and what have you, and that's great, but these things never cause them to lose sight of previous interests, which are pretty precious. I mean, why are nature programmes so popular on TV? Because they are beautiful, they are unexpected, they are true. They aren't trying to sell you anything or win your vote, they are nature and you know you are part of it. It's amazing to think how long it took for television to latch on to how popular natural history is and, in some countries, they still haven't. In Britain, however – thanks to the BBC, who started very early in the Fifties – wildlife programmes are now a huge thing.

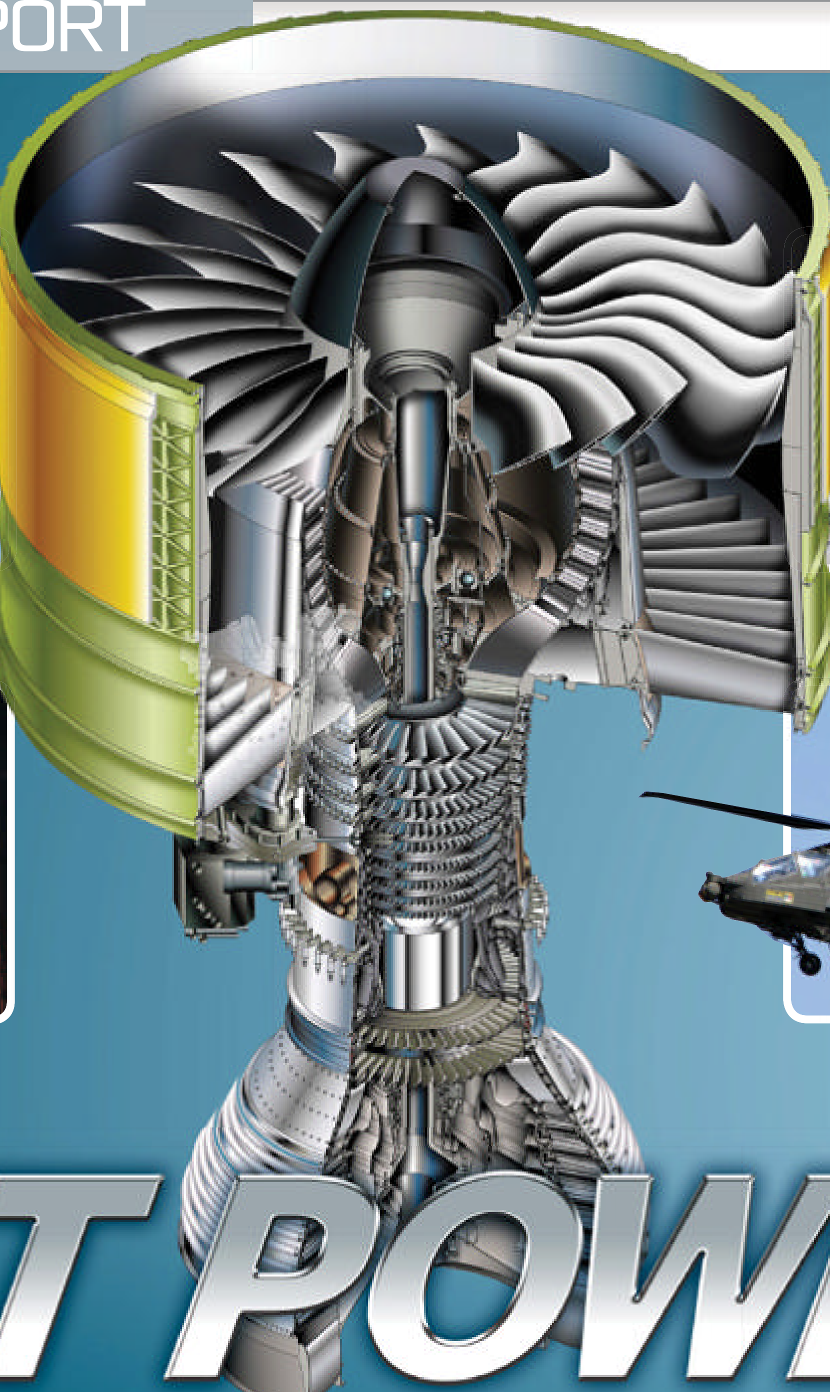
**HIW: A lot of filming for this series took place in the Natural History Museum. Was that a favourite place of yours growing up?**
**DA:** Oh yes! The Natural History Museum is a great, great place with loads of fossils. Although I do remember travelling all the way down from Leicester to see this dinosaur – a diplodocus – and when I got there I read the label and discovered it was a cast. I really felt betrayed and thought, 'That's not right, I want to see the real thing.' It wasn't until I went to the States that I saw a big sauropod like that. In retrospect, I think children can be very sensitive to that sort of thing.

**HIW: You must be one of the most well-travelled people on Earth. Is there one place you favour over all others?**
**DA:** Richmond in Surrey. My home.

**Sir David Attenborough's latest show *Natural Curiosities* premieres on 29 January 2013 at 8pm, on the Eden Channel (Sky 532/Virgin 208). For more information about the programme and Sir David Attenborough himself, visit www.exploreeden.co.uk.**

Sir David Attenborough studied Natural Sciences at Cambridge University, but his heart was always set on a more hands-on career rather than one in academia

AFTERBURNERS



TURBOPROPS

TURBOFANS

TURBOSHAFTS

# JET POWER

## From scramjets to turbofans, discover how a jet engine is based upon Isaac Newton's third law of motion

It's one thing to wrap your head around the physics of the Wright brothers' plane, but how do you generate enough power to sling a 350-ton Boeing 747 into the air and keep it cruising at 1,000-plus kilometres (640 miles) per hour? You strap yourself to four workhorse jet engines, that's how.

The modern jet engine represents the 80-year evolution of the gas turbine. A turbine is any kind of rotating device that extracts energy from a fluid flow and converts it into work. A windmill is a turbine that extracts energy from the wind to turn a shaft that can be used to grind grain. Steam turbines heat water to create high-pressure jets of steam that spin turbines to generate electricity. The power of a turbine is a product of the total mass flow of fluid – whether air, steam or water, etc – through the system and the efficiency with which the turbine converts this into energy.

A gas turbine is more complicated than a windmill or steam turbine as it adds combustion into the mix. Jet engines are a form of 'air-breathing' gas turbine, where the fluid (air) is compressed, mixed with fuel and burned at high temperature and pressure to create a flow of hot gas that spins the turbine. That's where the name 'jet' engine is derived from – the jet of hot gas that spins the turbine and streams out the back, creating a huge amount of thrust. ▶

## 5 TOP FACTS
## JET ENGINES

**Heavy-duty turbines**

1 To generate electricity, some powerplants use 100-ton gas turbine engines fuelled by natural gas. Residual heat can be used to boil water for a secondary steam turbine.

**Engine placement**

2 Airframe manufacturers are testing out novel engine configurations – eg flush with the fuselage, or two in the rear with no separation – to boost thrust and decrease drag.

**Hybrid rocket jet**

3 UK company Reaction Engines Limited is developing the first-ever rocket plane with an 'air-breathing' jet engine at low altitude and a rocket mode to leap into orbit.

**Jet-powered tank**

4 The US Army's M1 tank sports a gas turbine engine under the hood, providing enough thrust to go from 0-32 kilometres (0-20 miles) per hour in 7.2 seconds.

**Jet cars**

5 In the Sixties, some racers in the Indianapolis 500 drove cars combining a turboshaft helicopter engine with a four-wheel drive transmission. They were quickly outlawed.

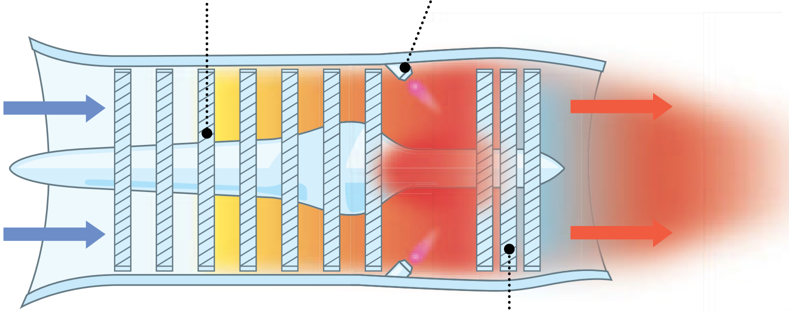
**DID YOU KNOW?** *You can buy miniature jet turbine engines to power remote-control aeroplanes!*

# Types of jet engine

We break down six of the most common jet engines to see how they produce thrust

## Turbojet

**Example:**
Cruise missiles



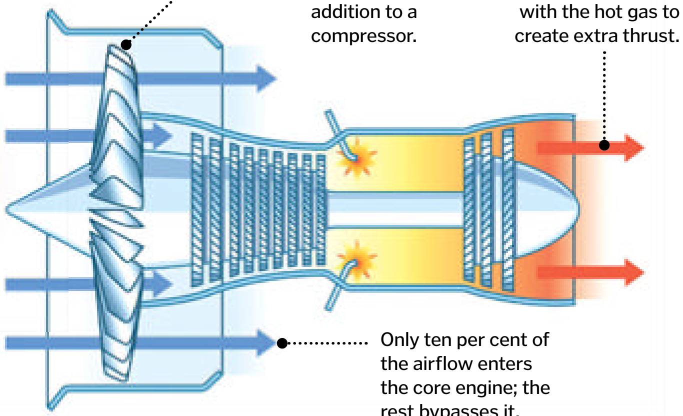
A series of bladed discs called a compressor draws in air and increases air pressure.

The compressed air is mixed with a small amount of fuel and ignited in a combustor.

Hot gas exits the combustor and spins a turbine, which powers the compressor up front.

## Turbofan

**Example:**
Passenger jets



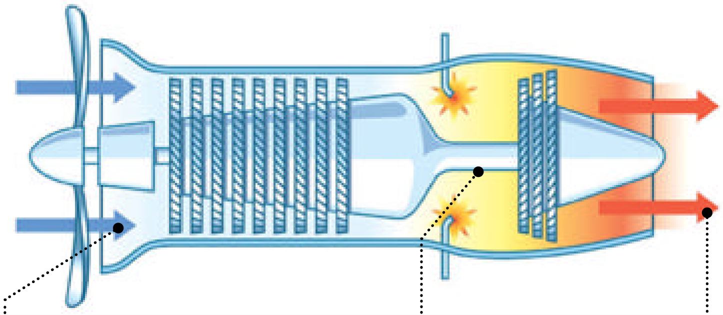
A large-bladed fan draws in air in addition to a compressor.

When exiting, cooler bypassed air mixes with the hot gas to create extra thrust.

Only ten per cent of the airflow enters the core engine; the rest bypasses it.

## Turboprop

**Example:**
Military/civil aircraft



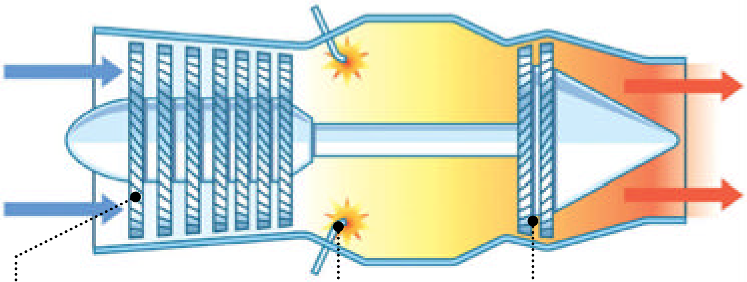
A portion of the airflow enters a conventional turbojet engine.

The hot gas flow exiting the combustor spins a turbine that powers the propeller.

The remaining hot gas flow is very weak; most of the thrust is delivered by the propeller.

## Turboshaft

**Example:**
Helicopters



Airflow and pressure are created by a multistage compressor.

Hot gas flow from the combustor turns a turbine, which transfers energy to a driveshaft.

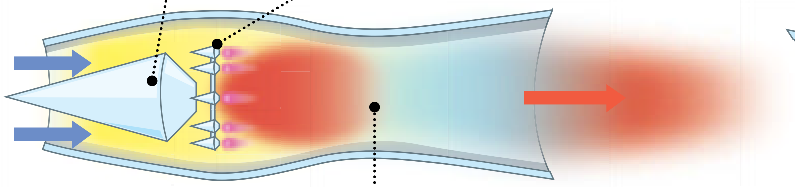
The driveshaft attaches to a gearbox, which can turn a horizontal helicopter blade.

## Ramjet

**Example:**
Missiles/weapons

Instead of using a compressor, the plane or missile's own velocity 'rams' air around a cone-shaped spike.

Fuel injectors combust the high-pressure air, which is stabilised by a flame holder ring.



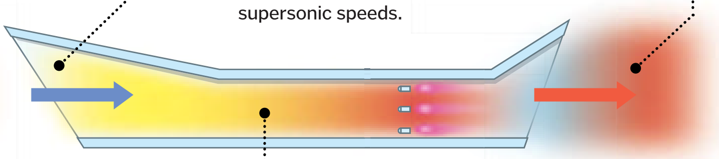
The hot gas flow passes through another nozzle, which reduces pressure and increases velocity.

## Scramjet

**Example:**
Experimental spacecraft

The reduced drag means greater fuel efficiency and greater thrust at super- and hypersonic speeds.

Like a ramjet, air is compressed with a cone-shaped intake at supersonic speeds.



Unlike a ramjet, a scramjet doesn't slow the airflow to subsonic speed for combustion.

© Pratt & Whitney; Thinkstock; Rolls-Royce PLC; Alamy

> "The biggest jet fans spin at 5,000 rpm and could suck all the air from a large arena in seconds"

The mechanics and physics of a jet engine are both elegantly simple and bafflingly complex. The best way to explain how they work is to dissect an engine and show how each part contributes to the immense thrust. The most common jet engine for passenger airliners is the turbofan. These engines are encased in a tube-shaped shell that tapers from front to rear. The opening of the shell is called the inlet, or intake, where the free air stream enters.

Nothing in a jet engine is designed as an afterthought. The lip of the intake on a turbofan engine is thick. That's because it must slow down the speed of the air stream when the plane is cruising. Think of a regular propeller, which is fully exposed to the free air stream. The propeller must work extra hard (and burn more fuel) to overcome fast-moving air as it rotates to create thrust. The large fan inside a turbofan engine works like a propeller, and the thick intake lip ensures the air enters at a constant speed. Supersonic jet engines are built with a long, sharp cone in front of the intake to 'shock' air to subsonic speeds before it enters.

The fan component of a turbofan engine employs 20 large blades turned by a central rotating shaft. The blades are airfoils like propeller blades, but curved into a scythe shape to maximise airflow. The role of the fan is to suck as much air as possible into the engine; the biggest jet fans spin at 5,000 rpm and could suck all the air from a large arena in seconds.

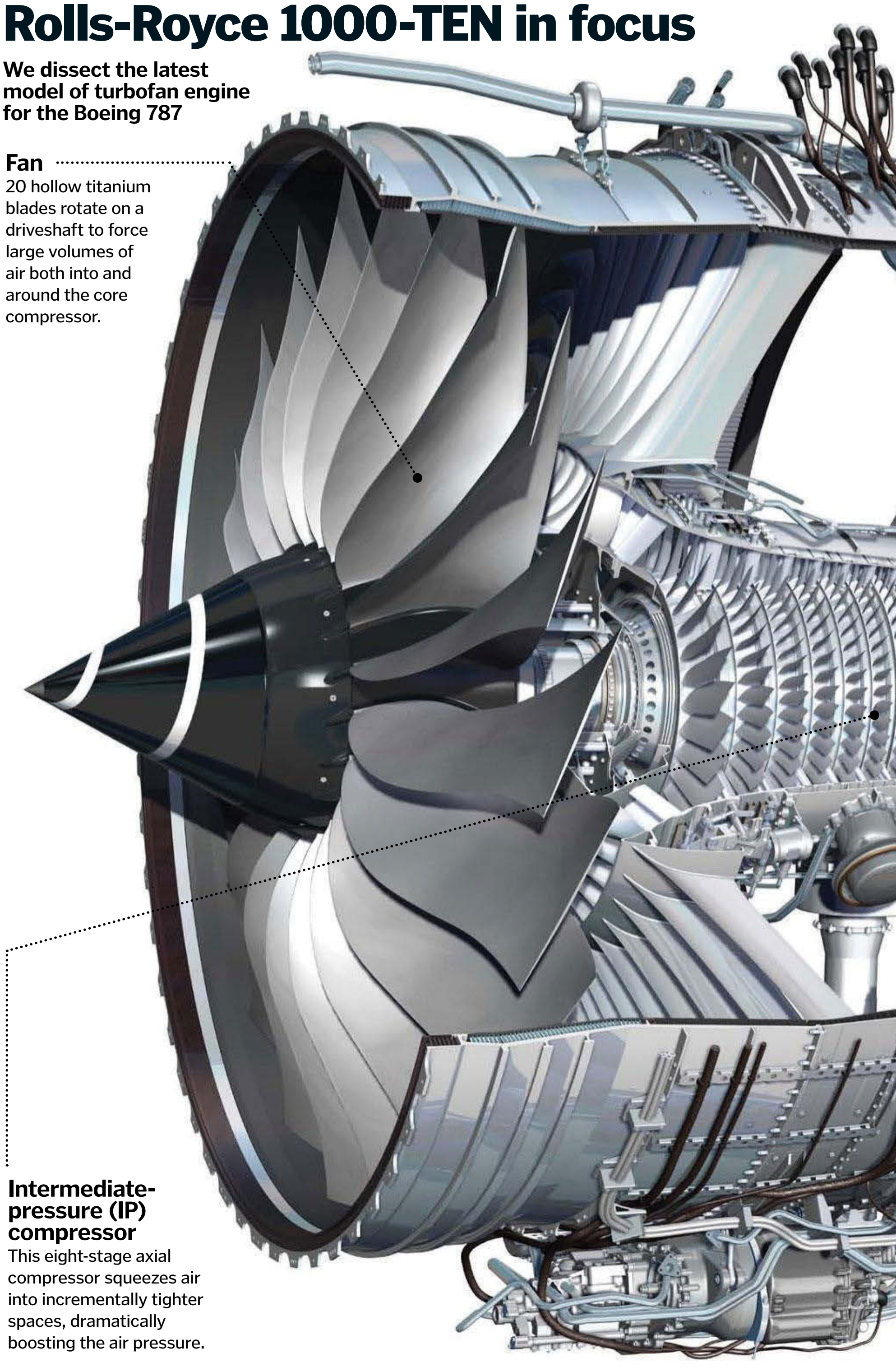
The air that is drawn into the engine is now compressed by a series of rotating discs with hundreds of small blades. The precision of these rotating discs is an engineering marvel. Again, each blade is a flawless airfoil, capitalising on Bernoulli's principle, which states that air passing below the blade has a higher pressure than air above the blade. As the incoming air flows from one whirling compressor stage to the next, the pressure mounts, squeezing an enormous volume of air into an increasingly smaller space.

According to the laws of thermodynamics, when a static volume of air increases in pressure, it also increases in temperature, so as the air moves through the compressor stage, it builds both in pressure and heat. Now it's time to light the fuse. A jet engine's immense power comes from the continuous combustion of an explosive mix of hot, pressurised air and jet fuel. The combustor itself is a doughnut-shaped tube with perforations to slow the flow of hot air. The combustor is ringed with a dozen or more fuel injectors that spray a precise mist of high-octane jet fuel. The fuel and hot air ignite at temperatures exceeding 815 degrees Celsius (1,500 degrees Fahrenheit), and the resulting superhot jet of exhaust gas runs smack into the turbines.

The job of the turbines in a turbofan engine is to convert some of the immense energy of combustion into mechanical rotary motion. Like the compressor, the turbines are arranged as multistage rotating discs fitted with hundreds of blades. Turbine blades need to withstand long periods exposed to extreme temperatures, so they are built from heat-resistant alloys and are perforated with tiny holes that channel cooler bypass air from the fan. The spinning turbines are connected by a central shaft to the ▶

## Rolls-Royce 1000-TEN in focus

**We dissect the latest model of turbofan engine for the Boeing 787**



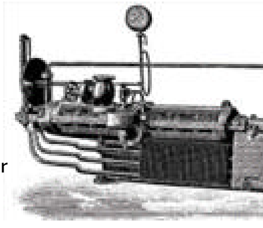
**Fan**
20 hollow titanium blades rotate on a driveshaft to force large volumes of air both into and around the core compressor.

**Intermediate-pressure (IP) compressor**
This eight-stage axial compressor squeezes air into incrementally tighter spaces, dramatically boosting the air pressure.

## Jetsetting through history

### 1884

**Full steam ahead**
In Charles Parsons' patent for the steam turbine, he describes a configuration in which a compressor feeds air into a furnace, which produces energy to power a turbine that returns energy back to the compressor – essentially a gas turbine!

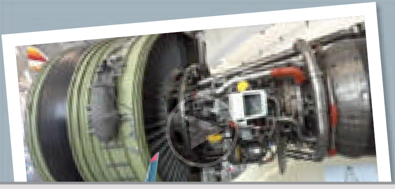


## AMAZING VIDEO!

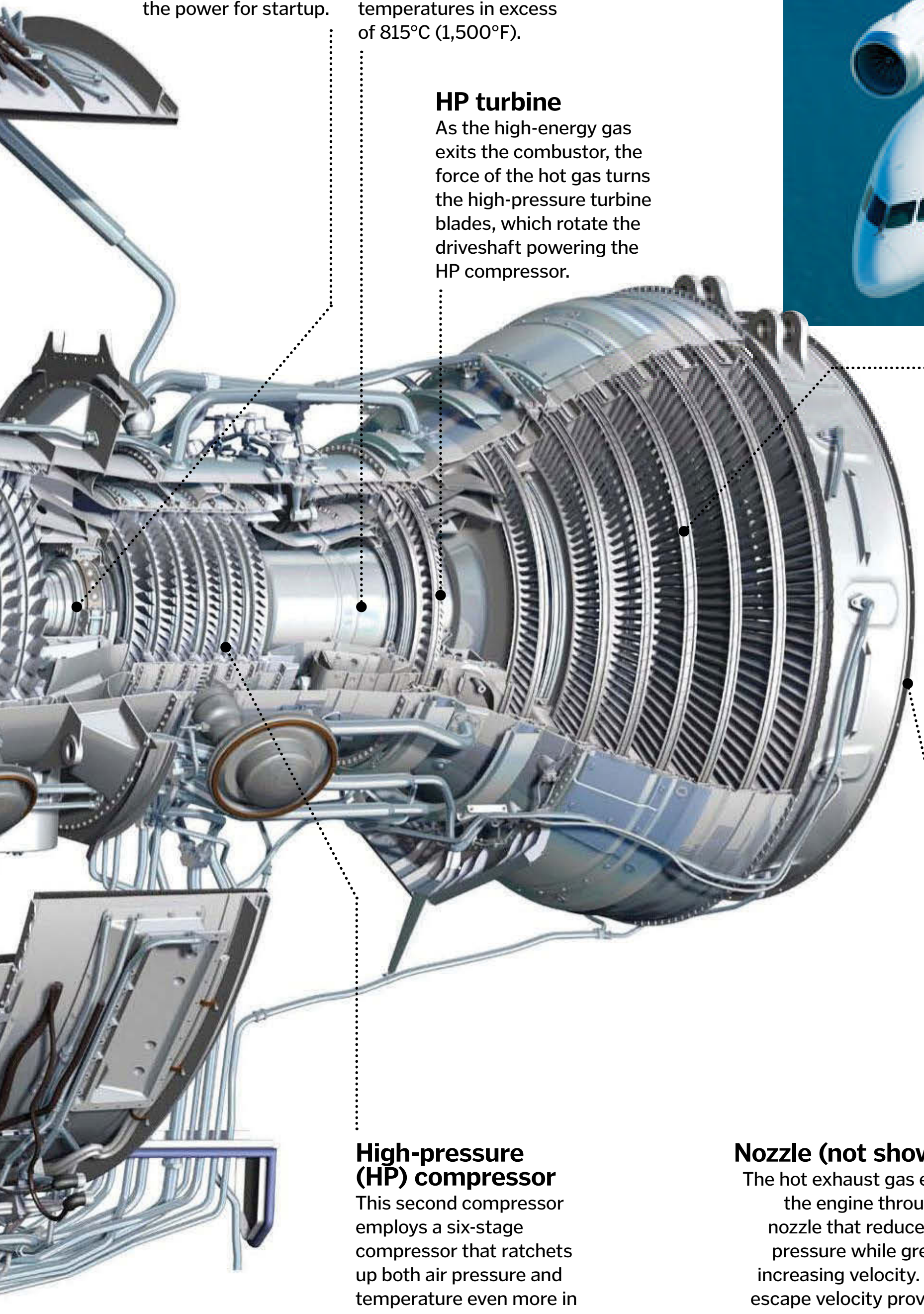
SCAN THE QR CODE FOR A QUICK LINK

**Explore the largest jet engine, the GE90-115B**

www.howitworksdaily.com



**DID YOU KNOW?** Each turbine blade in a Rolls-Royce Trent jet engine is designed to last for 8mn km (5mn mi) of flying



### IP power offtake

The rotational force of the IP compressor blades is used to turn turbines in an electrical generator that produces the power for startup.

### Combustor

Jet fuel is injected into this doughnut-shaped chamber, where it mixes with the hot, compressed air before igniting at temperatures in excess of 815°C (1,500°F).

### HP turbine

As the high-energy gas exits the combustor, the force of the hot gas turns the high-pressure turbine blades, which rotate the driveshaft powering the HP compressor.

### Low-pressure (LP) turbine

A residual flow of high-energy gas passes through the HP turbine and enters the LP turbine. These rotating blades turn the driveshaft that powers the turbojet fan at up to 5,000 rpm.

### High-pressure (HP) compressor

This second compressor employs a six-stage compressor that ratchets up both air pressure and temperature even more in preparation for combustion.

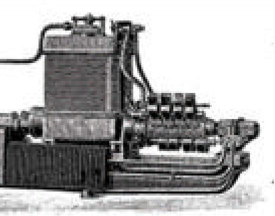
### Nozzle (not shown)

The hot exhaust gas exits the engine through a nozzle that reduces air pressure while greatly increasing velocity. This escape velocity provides the engine's thrust.

## Fan blade physics

All fan and compressor blades in a turbofan engine are airfoils, meaning they have an elliptical leading edge like a conventional propeller blade. The tapered shape follows Bernoulli's principle, forcing the air to move faster over the curved 'top' of the blade, reducing pressure and creating lift or thrust from 'below'. Turbofan blades are also long and wide, giving them a large surface area. When 20 blades with a six-metre (20-foot) diameter are spinning at the same time, they can move around 1,100 kilograms (2,400 pounds) of air per second, producing significant thrust.

Turbofan blades are also 'ducted fans', which means the spinning blades are housed within a cylindrical duct rather than rotating freely. Ducted fans have the advantage of reducing a drag effect called wingtip vortices. When an elliptical wing cuts through the air, it leaves a spinning trail of air called a vortex. That vortex increases drag, vibration and noise. Ducted fans prevent this and, as a result, are quieter, run smoother and can create the same amount of thrust with shorter blades.



## 1926

### Turboprop origins

AA Griffith publishes a seminal paper on axial compressors built with airfoil-shaped blades. The paper includes a basic diagram of a turboprop engine.

## 1929-1930

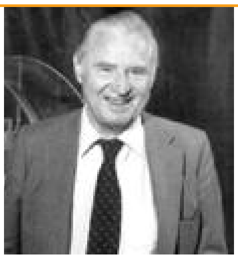
### Turbojet turned down

English engineer and pilot Frank Whittle submits designs for a turbojet engine to the Air Ministry, which rejects the design for a mathematical error. Whittle gets a patent instead.

## 1933

### German jet

With no knowledge of Whittle's design, German engineering student Hans von Ohain writes a paper proposing a strikingly similar jet engine.



© Boeing; Rolls-Royce PLC

> "Turbofan engines get thrust from two sources: the exhaust gas and the bypass air stream"

compressor and fan components. In fact, it's the rotary motion of the turbines that powers both the compressor and the fan, creating a highly efficient closed loop. Turbines can power more than compressors and fans though. In turboshaft jet engines, the turbines are connected to a secondary gearbox that powers a propeller blade – that's how helicopters like the AH-64 Apache get their speed.

The turbines absorb some of the energy from the exhaust gas, but not all of it. The rest is directed through the rear nozzle. The tapered shape of the nozzle plays a critical role in producing thrust. The idea is to slightly restrict the flow of the exhaust gas, building up pressure before releasing it. When the highly pressurised air enters the free air stream, pressure drops steeply, which translates into high velocity. In compliance with Isaac Newton's third law of motion – every action (force) in nature has an equal and opposite reaction – as high-velocity exhaust gas escapes from the back of the engine, it essentially pushes the plane forward.

Turbofan engines are so efficient because they get thrust from two sources: the exhaust gas and the bypass air stream. If you remember, the huge fan in the front of the engine only forces a portion of its air into the compressors. The rest – a 9:1 ratio on bigger engines – bypasses the engine core, flows through the shell and exits through a special double-barrel nozzle paired with the exhaust gas. It's the combination of the huge fan – which acts like 20 propellers moving 1,088 kilograms (2,400 pounds) of cool air per second – and the hot exhaust gas that makes turbofans the top choice for long-haul passenger and cargo planes.

Fighter jets and other supersonic craft have engines that sacrifice fuel efficiency for raw power. When high-speed aircraft approach the speed of sound, drag increases significantly. To provide extra thrust, supersonic jet engines are armed with afterburners. The afterburner is a ring of fuel injectors located behind the turbines, directly in the hot exhaust stream. Afterburners combust the exhaust gases a second time, generating even higher exit velocities.

To exceed Mach 5, engineers are experimenting with ramjet and scramjets with no fans, compressors or turbines. Instead, air is forced into the cone-shaped intake by the speed of the craft and compressed. Fuel injectors combust this air and hot exhaust gas explodes out of a convergent-divergent nozzle. Ramjets and scramjets must be launched by rocket engines or released from other supersonic craft. NASA's unmanned X-43 used a scramjet to reach Mach 9.6 (11,760 kilometres/7,310 miles per hour) in 2004, the fastest speed ever achieved by an air-breathing jet engine.

## Is bigger always better?

A bigger engine is not necessarily more powerful. The thrust-to-weight ratio is a measurement of the power of a jet engine for its size. An engine with a high thrust-to-weight ratio produces a lot of thrust for its size, while an engine with a low thrust-to-weight ratio is generally less powerful, but not necessarily less efficient. What's the difference? Well, for commercial airliners and cargo planes, the vast majority of the flight is spent in cruising mode. To maintain cruising speed, the engine needs to produce just enough thrust to overcome drag. Large turbofan engines, which have a low thrust-to-weight ratio, are the most efficient for this task, because the large fans burn less fuel while providing sufficient thrust. Fighter jets, on the other hand, need a high thrust-to-weight ratio in order to pull off high-speed manoeuvres and near-vertical climbs. The afterburners employed by fighter jet planes generate tremendous thrust, but consume bucketloads of fuel. In the turbofan example, a large mass of gas (air) is accelerated a small amount. In the fighter jet example, a relatively small amount of air is accelerated a large amount. Different engine designs can be tailored to other users' requirements.

**LiftSystem**
The power delivered by the F135 engine is directed through the F-35's LiftSystem, which combines a LiftFan with a thrust vectoring nozzle to allow STOVL (short take-off vertical landing) manoeuvres.

### 1939

**Maiden jet flight**
With the support of German plane manufacturer Heinkel, Von Ohain's improved turbojet design is the first to be built and tested. The first jet-propelled aircraft, the Heinkel He 178, flies in August 1939.

### 1941

**British jet**
After a decade of setbacks, Whittle finally sees his jet engine take flight on the Gloster E.28/39 – the first British-built jet-powered plane.

### 1942

**Deadly Swallow**
The German Messerschmitt Me 262 – aka the Swallow – becomes the first jet-propelled fighter aircraft, claiming 542 Allied kills in WWII.

**RECORD BREAKERS**
**SVELTE ASSASSIN**

# 11.476:1

## HIGHEST THRUST-TO-WEIGHT RATIO

The Pratt & Whitney F135 is a lean machine – with 40 per cent fewer parts than other fighter jet engines – designed for the next-gen F-35 Lightning II vertical-liftoff attack fighters.

**DID YOU KNOW?** *The lift fan on the F-35 Joint Strike Fighter generates 9,070kgf (20,000lbf) of thrust for takeoff and landing*

A Rolls-Royce Trent 1000 turbofan engine rolls off the assembly line. These engines are currently being equipped to the Boeing 787 Dreamliner

**Performance**
Combined with the F-35's streamlined fuselage, the aircraft's engine can propel it to a top speed of Mach 1.6 (1,900km/h; 1,200mph) with superb efficiency.

**Engine**
The F-35 Lightning is equipped with a Pratt & Whitney F135 afterburning turbofan capable of a maximum thrust of 19,500kgf (43,000lbf).

## Jet engines in numbers…

**2,000**
Jet fuel can burn at up to 2,000°C (3,632°F), but is instantly cooled by air intake holes and pressure release

**58,015**
The GE90 holds the world record for the highest recorded thrust at a whopping 58,015kgf (127,900lbf)

**325**
General Electric's GE90 turbofan engine boasts fan blades with a 325cm (128in) diameter

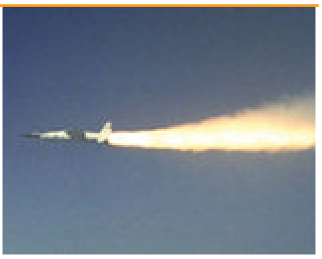
**4**
The Rolls-Royce Trent 1000-TEN could suck all the air from New York's Madison Square Garden in just four seconds

**1,100**
The nickel alloys used to build nozzle guide fans cope with temperatures as high as 1,100°C (2,012°F)

### 1952
**Comet takes off**
The British-made de Havilland DH 106 Comet becomes the world's first commercial passenger jet aeroplane sparking a new era of global travel.

### 1976
**Concorde's debut**
The Concorde SST becomes the first supersonic passenger jet, travelling from London to New York in only three and a half hours at twice the speed of sound.

### 2004
**Enter the hyperjet**
The X-43, an unmanned experimental NASA aircraft, employs a Hyper-X scramjet engine to achieve Mach 9.6 (11,760km/h; 7,310mph).



© Steve Fitzgerald; Rolls-Royce PLC; Lockheed Martin

> "If the unique fob receives the signal and returns the correct encrypted response, the car's doors will unlock"

# The secrets of keyless cars

## Discover how cars can be unlocked and started up automatically without a key

Keyless ignition systems work on two levels. Firstly, the driver's key fob is upgraded so it acts as a radio transceiver. This allows the fob to both transmit and receive radio signals, with each passing between the vehicle and the fob over a certain distance. Secondly, the vehicle itself is equipped with a series of internal and external antennas, which can likewise send and receive encrypted radio signals. The encryption, which is typically dynamic, prevents signals from being easily intercepted and used to gain illegal access.

When the external antennas detect a key fob in close proximity, an encrypted radio signal is transmitted at a specific frequency (generally between 315 and 433 megahertz). If the fob, which is unique to each vehicle, receives the signal and returns the correct encrypted response, the car's doors will unlock and engine systems will be primed. Once the driver gets in, the array of internal antennas sends another encrypted radio signal to the fob, querying it for a different response. If this is cleared, the immobiliser is turned off and an 'on' button can be hit to start up the engine.

The 2013 Ford Mondeo is one of the latest cars to employ keyless tech, though the first example dates back to 1980 in the Renault Fuego Turbo

# How do wheel clamps work?

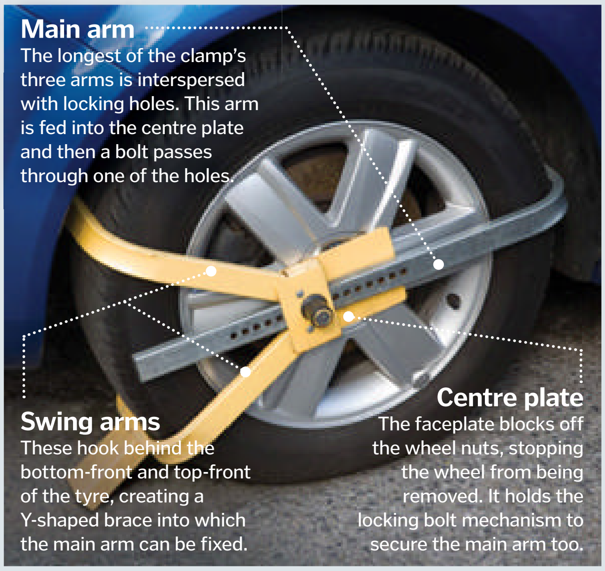
## Learn how these devices ensure illegally parked vehicles can't make a quick getaway

Wheel clamps, once called auto immobilisers, come in a variety of configurations, but each works by preventing 360-degree rotational movement without seriously damaging the vehicle. This is achieved by enclosing one wheel in a Y-shaped brace consisting of a central faceplate, main arm and pair of swing arms.

The central faceplate's function is twofold. First of all, it prevents access to the wheel nuts, which otherwise could be removed if left uncovered, allowing the wheel to be taken off entirely and replaced with a spare. Secondly, the plate also provides a protective barrier for the clamp's locking mechanism, so this can't easily be tampered with.

The main arm of the clamp, which can either be a separate component to the centre plate and swing arms or part of a single unit, acts both to prevent backward wheel rotation and also to enclose the wheel as tightly as possible. It achieves the latter by slotting through the faceplate's locking mechanism before being secured by a bolt.

The swing arms complete the Y-shape lock and can dynamically rotate from the central plate. These arms sit at the bottom-front and top-front of the clamped wheel, hooking around the tyre to form a three-point brace. On certain models the swing arms can also be extended or retracted so the clamp fits a wider variety of wheels.



**Main arm**
The longest of the clamp's three arms is interspersed with locking holes. This arm is fed into the centre plate and then a bolt passes through one of the holes.

**Swing arms**
These hook behind the bottom-front and top-front of the tyre, creating a Y-shaped brace into which the main arm can be fixed.

**Centre plate**
The faceplate blocks off the wheel nuts, stopping the wheel from being removed. It holds the locking bolt mechanism to secure the main arm too.

© Ford Motor Company; Alamy

## 5 TOP FACTS: AGUSTAWESTLAND MERLIN HC3

An AgustaWestland Merlin was featured in an explosive scene as it hunts Bond at a Scottish country lodge during the agent's 23rd film, Skyfall.

The cabin can carry up to 24 fully equipped combat troops and when required, will convert to carry 16 stretchers for casualty evacuation or during humanitarian and disaster relief operations.

It is also fitted with an active vibration-damping system, which reduces the level of noise and vibration inside the cabin. As a result, crew fatigue is much reduced during long transits and airframe life is increased.

Designed to operate away from base workshops and in difficult terrain, the Merlin has state-of-the-art support technology and incorporates aircraft health-and-usage diagnostics and a self-test capability.

Merlin has the capacity to carry up to four homing torpedoes, such as the Stingray torpedoes or Mk11 depth bombs.

# AIRFIX How it works

Scan this QR code with your smartphone to find out more!

The cutting-edge rotor design allows for higher take-off weights than previous helicopters.

The large ramp, unique to RAF Merlin's allows for cargo to be easily loaded.

As they operate with special forces, WMIKS are often supplied from the air.

The Merlin's extensive avionic and defensive aid suite help it to remain safe in hostile skies.

General purpose machine guns provide the Merlin with offensive capability.

## AGUSTAWESTLAND MERLIN HC3 - NEW

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> "When a car needs attention, the team's communications crew calls the vehicle in to the pits"

# F1 pitstops up close

## What happens during a pitstop and how are repairs made so rapidly?

A pitstop is a motorsport operation where a racing car – such as those used in Formula 1 – is refuelled, fixed, adjusted or gets a new driver. In an F1 context, a pitstop generally entails changing the car's wheels and topping up its fuel tank.

Pitstops are carried out, not surprisingly, in the pits, a segment of track that runs parallel to the main circuit's starting grid, and is broken down into a series of bays. Each bay is assigned to a Formula 1 team, with a bay consisting of an internal garage and an external, pit-side operations area – the latter marked by coloured lines.

When a car needs attention, the team's communications crew calls the vehicle in to the pits, which involves the driver completing their current lap and then entering the pit lane. For safety, a set speed limit is imposed within the pit lane of 100 kilometres (62 miles) per hour. The driver then proceeds down the lane and is flagged into their bay by a sign-waving crew member. This allows the driver to quickly enter their box both smoothly and safely, which is critical as time is of the essence.

As soon as the driver is stationary within their bay's designated guidelines, operations can begin (see the 'Anatomy of a pitstop' boxout for a detailed breakdown). Once any repairs and adjustments have been completed, the car is released to travel to the end of the pit lane and then the circuit proper, where it merges back into the racing pack. ⚙

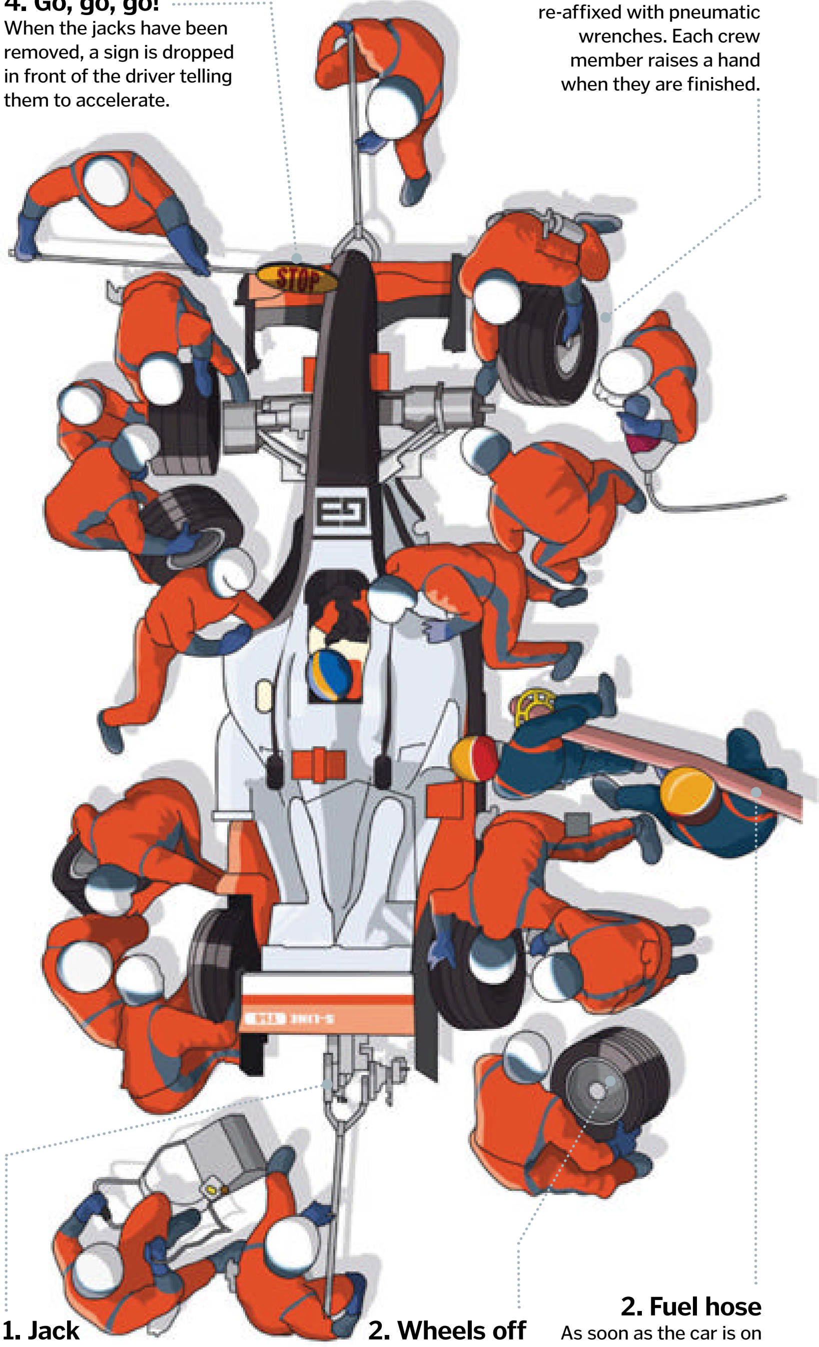
The driver must stop within a predefined box, otherwise the crew has to reposition, losing valuable seconds

## The need for speed

In Formula 1 the difference between a podium position and mid-table obscurity can be a matter of seconds – or even milliseconds. As such, each pitstop a vehicle needs to take must be as fast as possible, as even a slight hitch can see the driver's position on the track severely lowered. To combat this every F1 team's pit crew undertakes weekly training routines during a season, each simulating a typical pitstop, to ensure they are working in the most efficient way possible. These routines include standard tyre changes and refuelling operations, right through to rarer or more complex operations involving repairs or mechanical adjustments. The current world record for a four-wheel tyre change is held by McLaren F1, who during the 2012 German Grand Prix completed a switch in just 2.31 seconds – a whole second and a half ahead of the average four seconds taken over the race as a whole.

## Anatomy of a pitstop

**We break down the key operations carried out in a lightning-quick Formula 1 pitstop**



**4. Go, go, go!** When the jacks have been removed, a sign is dropped in front of the driver telling them to accelerate.

**3. Wheels on** Once the four old wheels are taken off – each by a dedicated handler – four new ones are installed and re-affixed with pneumatic wrenches. Each crew member raises a hand when they are finished.

**1. Jack** The moment the car is stationary in the pit a series of jacks is used to lift it off the ground. This allows the tyres to be changed.

**2. Wheels off** All four wheels are removed with pneumatic wrenches within just a couple of seconds at the same time as the fuel hose is inserted.

**2. Fuel hose** As soon as the car is on the jacks a dedicated team accesses the fuel port and inserts a high-speed hose to quickly refill its tank.

© Getty; Alamy

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> "Cargo ship holds cut through several tiers of the vessel to create a massive, insulated storage bay"

# On board a cargo ship

Capable of carrying thousands of tons of goods, these giants of the sea are as technically complex as they are enormous

There are several kinds of cargo ship, each specialising in carrying various goods in tailored ways. But in general they can be identified by three key features.

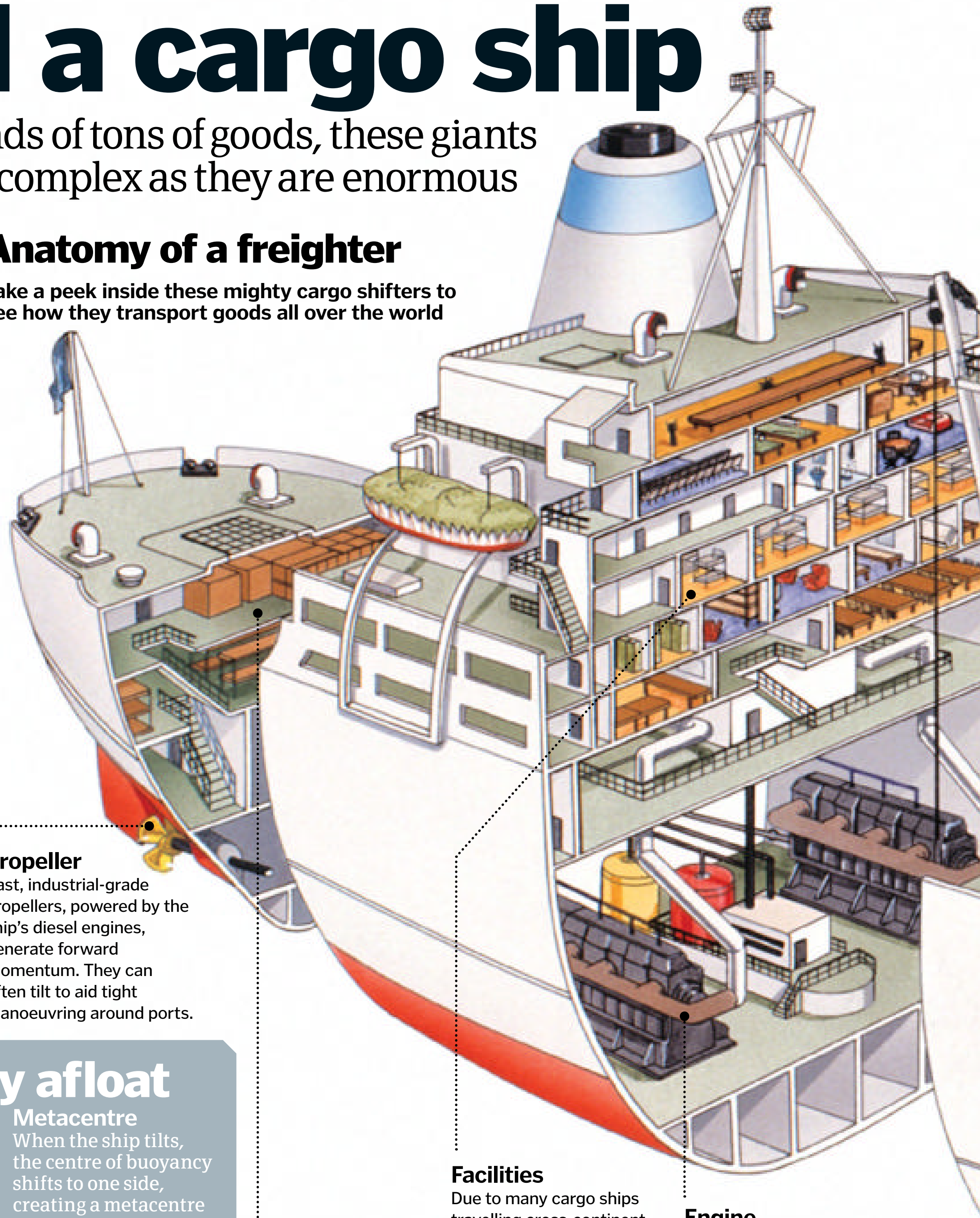
The first of these are deck cranes, static lifting platforms that specialise in distributing freight on and off the vessel, as well as into the ship's deep cargo hold. There are two main sorts: single, side-mounted deck arms – which often pivot on a hydraulically powered base, or inverted U-frames, where a grabbing arm moves horizontally between two fixed struts.

Another major feature, not surprisingly, is a large hold. These are typically located in the centre of the deck – though additional holds are sometimes included – and cut through several tiers of the vessel to create a massive, insulated storage bay. Containers are lowered into a hold via deck cranes or others situated on the port.

Lastly, cargo ships can be distinguished by their generally huge size – particularly notable in the height of their hulls when unladen. The latter design works to offset the extreme weight they carry when loaded, with a vast proportion of the hull submerged. This helps to maintain stability while manoeuvring under full load, the physics of which we look at in closer detail in the 'How cargo ships stay afloat' boxout.

## Anatomy of a freighter

**Take a peek inside these mighty cargo shifters to see how they transport goods all over the world**



**Propeller**
Vast, industrial-grade propellers, powered by the ship's diesel engines, generate forward momentum. They can often tilt to aid tight manoeuvring around ports.

**Facilities**
Due to many cargo ships travelling cross-continent to deliver their goods, a number of basic facilities are provided for the crew for rest and recreation.

**Engine**
Twin diesel-fuelled generators create a huge amount of horsepower to drive the ship's propulsion.

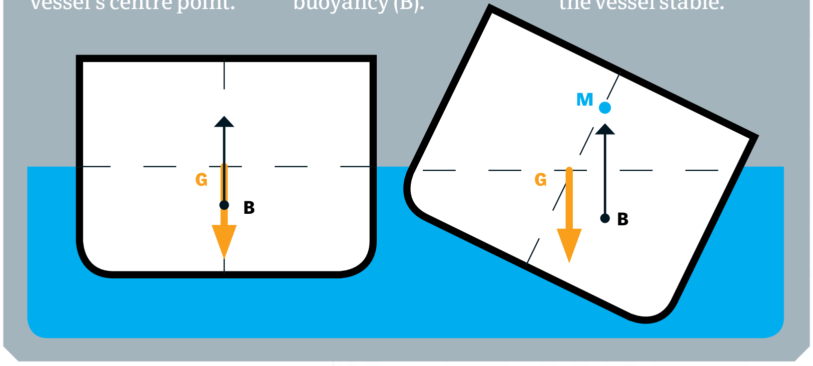
**Auxiliary hold**
Larger cargo ships may be equipped with more than one hold. These auxiliary storage areas are typically located at the front and/or back.

## How cargo ships stay afloat

**Mass**
The weight of the ship's cargo acts upon it through the ship's centre of gravity (G). When level, this is directly through the vessel's centre point.

**Buoyancy**
The weight of the cargo is counteracted by the force of the water that's displaced by the ship's hull, which acts upward through the centre of buoyancy (B).

**Metacentre**
When the ship tilts, the centre of buoyancy shifts to one side, creating a metacentre (M) that compensates for the offset, keeping the vessel stable.



RECORD BREAKERS
FREIGHT RATE

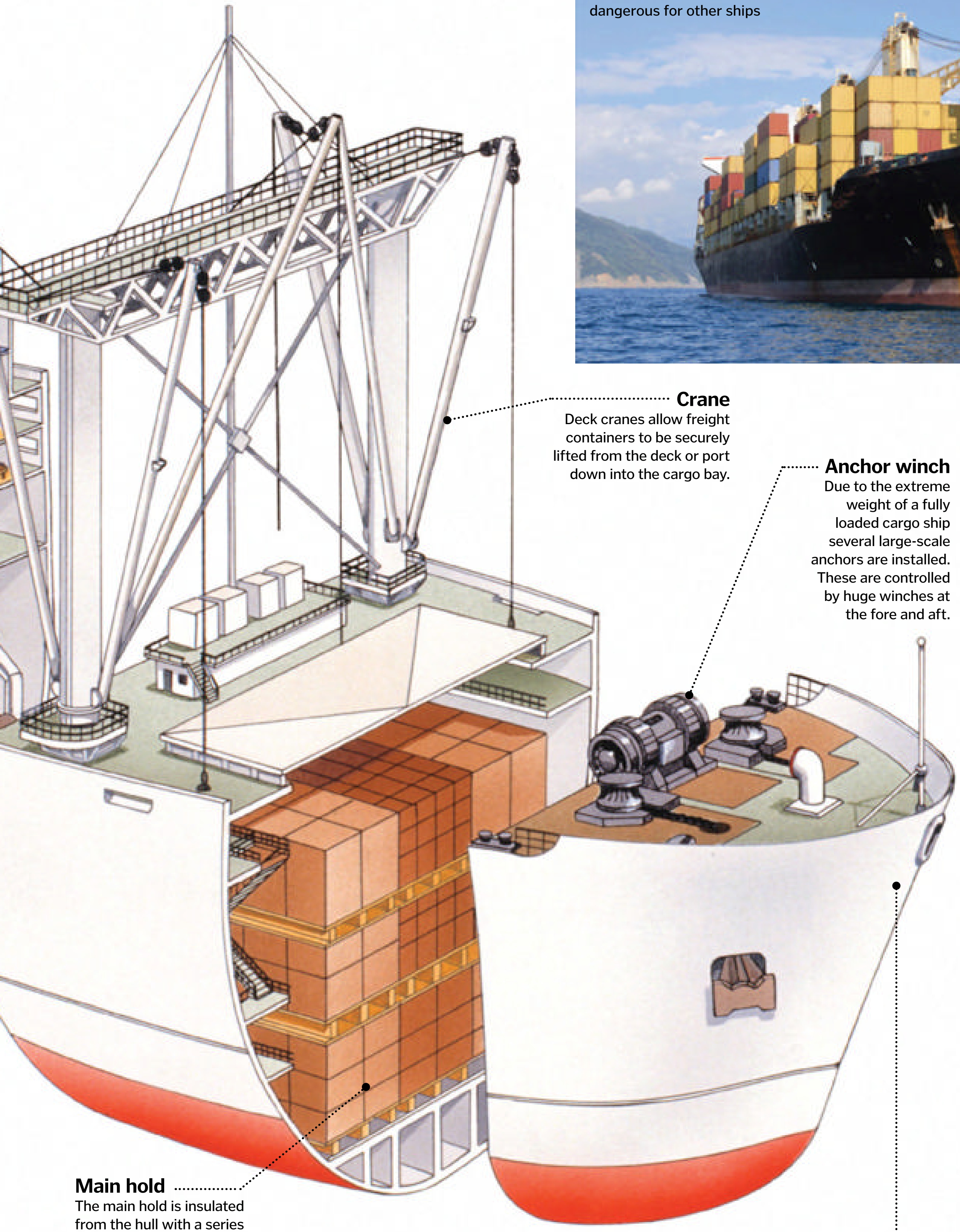
# 13,500

## WORLD'S LARGEST CONTAINER SHIP

This is the number of freight containers that the planet's biggest container ship – the Edith Maersk – can carry at any one time. The Danish-built vessel measures 397 metres (1,302 feet) long.

**DID YOU KNOW?** *The longest ship ever built was the ULCC Seawise Giant supertanker, which measured 458.5m (1,504ft)!*

It's estimated up to 10,000 containers a year are lost overboard, which can prove dangerous for other ships



**Crane**
Deck cranes allow freight containers to be securely lifted from the deck or port down into the cargo bay.

**Anchor winch**
Due to the extreme weight of a fully loaded cargo ship several large-scale anchors are installed. These are controlled by huge winches at the fore and aft.

**Main hold**
The main hold is insulated from the hull with a series of protective enclosures. It is accessed through a top-mounted deck hatch.

**Hull**
A large, tall hull is structurally reinforced to protect internal cargo and keep the ship stable in rough seas while laden.

## The cargo ship family

**1 Cargo ship**
A catchall term, cargo ships are typified by deep hulls and deck cranes.

**2 Oil tanker**
Oil tankers are notable for their lack of cargo hatches and minimal external handling gear. They consist of a series of internal, discrete tanks, a double hull and they feature very tall hulls.

**3 Dry bulk carrier**
Long and relatively flat vessels – like big barges – dry bulk carriers specialise in transporting coal, grain, ore and other loose, dry products.

**4 Container ship**
The easiest carrier to recognise, container ships carry freight containers openly on their large decks. They may or may not have deck cranes, but will sit low in the water when fully laden.

**5 Roll-on/off ship**
This vessel specialises in carrying moving vehicles, with a hydraulically powered rear ramp leading to multiple tiers of parking. Like ferries they sit high in the water.

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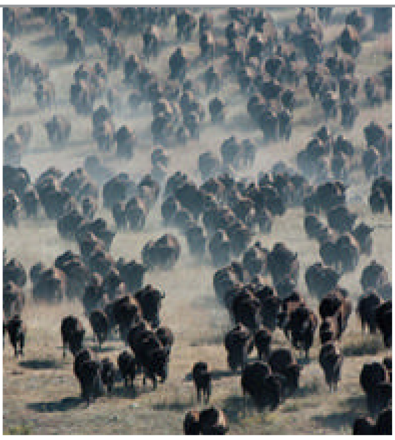


# Swarms

From bees to bison, animals all over the world find safety in numbers – mind-bogglingly huge numbers…

Birds of a feather flock together. But why exactly? It's not just birds – mammals, reptiles, amphibians, fish, insects and even bacteria all do it. Virtually every corner of the animal kingdom has found that banding together is a great tactic for surviving in the wild. As with everything else in nature, it boils down to two things: finding enough food and avoiding becoming food for something else. Swarming can help with both.

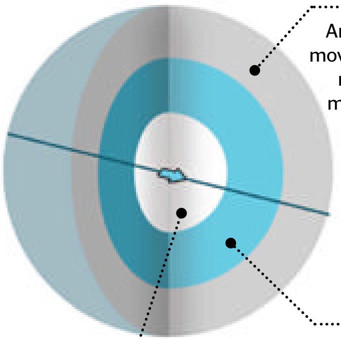
Herring, for example, feed on copepods. These tiny crustaceans, one or two millimetres (0.04-0.08 inches) long can shoot suddenly sideways for a couple of centimetres to evade an approaching fish. Herring aren't agile enough swimmers to react to this jump, so instead they swim in large schools with the gap between fish synchronised to the jump distance of the copepod. This increases each fish's chance of a meal because if a copepod leaps out of the path of one fish, it lands directly in front of another.

At the other end of the food chain, another marine crustacean – the krill – swarms to avoid predation. A large swarm of randomly swirling krill makes it much harder for fish to pick out any single target. Ironically, krill swarms are so huge that it has become viable for a much larger kind of animal – the baleen whales – to evolve the specialised apparatus for straining out several tons of krill in a single gulp. Ironically the very behaviour that protects them from small fish and penguins makes them vulnerable to the biggest creatures of them all.

Swarming also helps because it increases the number of eyes and ears on the alert for danger. A herd of wildebeest or a flock of seagulls allows each member to borrow the senses of the other animals as a sort of long-range radar. There's no need for direct communication; simply keeping up with the rest of their neighbours means that when one end of the group spots danger, the whole swarm wheels away from the threat ▶

## Modelling the swarm

**When all the individual members of a group adopt one particular combination of the attract, align and avoid rules below, a convincing swarm is simulated**



**Attract**
Animals will try to move closer to their neighbours. This makes the swarm tend to clump together.

**Avoid**
To prevent collisions, animals will be repelled by any neighbours that stray too close.

**Align**
Once they get close enough to a neighbour, the animal will try to move in the same direction.

## STRANGE BUT TRUE

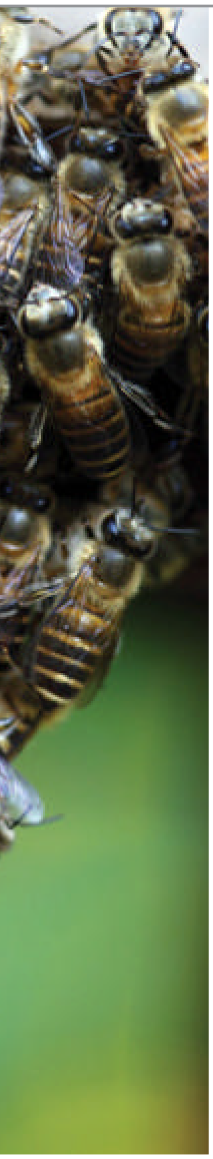
**IN FOR THE KRILL**

### On average how long do krill live for?

**A** 9 months **B** 10 years **C** 7 days

**Answer:**
For such a small animal, krill have a surprisingly long life span of up to a decade. Females can lay 10,000 eggs – sometimes several times a year. This explains how krill are able to form such huge swarms, despite the mighty appetites of whales.

**DID YOU KNOW?** *In 1958, one of the largest locust swarms ever recorded ate 167,000 tons of crops in Ethiopia*

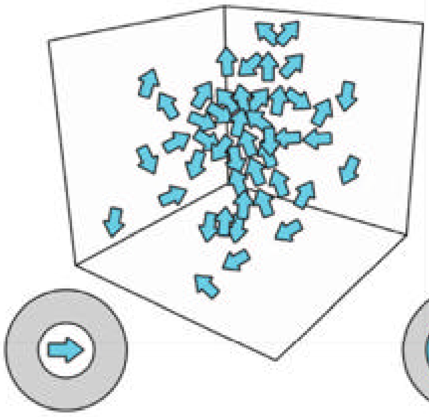


# Collective consciousness in focus

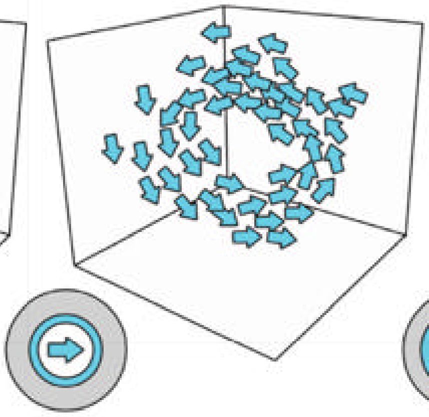
Each of your brain cells has no intelligence by itself. But connected together in sufficient numbers, they display remarkable new properties. In a similar way, a swarm of animals exhibits behaviours that go far beyond the reasoning abilities of individuals. Honeybee swarms will invariably choose the best site for a new hive, even though each bee will have personally visited, at most, one of the potential sites and so can't compare it with any others. Decisions are made by means of a positive feedback loop, with more of the returning bees 'voting' enthusiastically for the better sites through their special dance.

The way a swarm moves together as a coherent unit might seem like it involves a high degree of communication and leadership. But there is actually no centralised control. Ants, for instance, will follow a pheromone trail laid on the forest floor. But as they walk they also lay down a trail of their own. This makes the scent trail more powerful and the path becomes more popular. Like a stream cutting an ever-deeper valley as it flows downhill, the ant colony reinforces the popular routes and the swarm sticks together without any individual ant actually marshalling their movement.

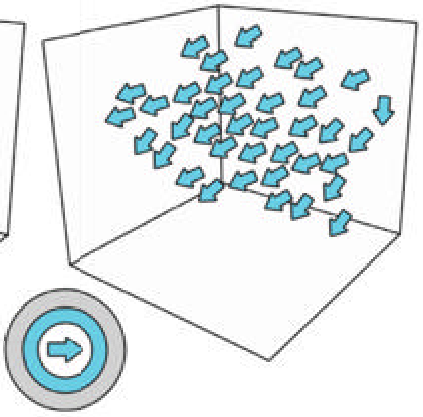
Even the more complex animals such as birds form swarms on the basis of surprisingly simple rules. Starlings, for example, simply try to fly in the same direction as their closest six or seven neighbours. But the result is a swirling cloud of birds that appears to have a collective mind of its own.



**Cloud**
Modelling a swarm with just 'attract' and 'avoid' zones creates a swirling cloud that's similar to a chaotic swarm of gnats.



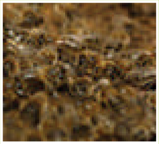
**Whirlpool**
Adding in the 'align' zone can lead to swirling circles. Some fish behave in this way to confuse predators.



**Flock**
By increasing the width of the 'align' zone, coherent flocking behaviour emerges naturally in the simulation.

## A perfect swarm

### Animal: Bee
### Swarm technique: Swarm



Honeybees swarm when the colony grows too big for its current hive. The queen and up to 60 per cent of the worker bees leave the hive and settle on a tree branch a few metres away. Other workers scout out possible new nest sites over the course of a few days and then the swarm flies together to establish a new colony.

### Animal: Locust
### Swarm technique: Swarm

Locusts are the final adult stage of certain grasshopper species. In crowded conditions, the grasshoppers will change into a ravenous, fast-breeding form. The population quickly explodes into swarms of billions and each locust will eat its own body weight in plant matter every day. Large locust swarms can cover an area the size of Greater London.

### Animal: Starling
### Swarm technique: Flock

Starlings are highly social birds and will often congregate in large flocks of up to a million. This reduces the risk of predation from birds of prey as they move between roosting sites and feeding grounds, because the swirling mass is hard to target. Flocks often contain individuals from different species of starling.

© Corbis; Getty; Thinkstock

> "At about 74 locusts per square metre, they stop changing direction altogether and march like an army"

as if it were a single organism. In fact, it's possible that multicellular life itself began as nothing more than swarming behaviour. Dictyostelid amoebae (a form of slime mould) live the ordinary, solitary life of a single-celled organism when food is abundant. But when it runs out, they secrete a chemical signal called cyclic adenosine monophosphate (cAMP) that attracts other nearby Dictyostelids. At a certain critical mass, the amoebae form into a multicellular 'slug' up to four millimetres (0.16 inches) long and move off in search of new food. The 'slug' has a definite front and back end and moves towards heat, light and humidity. It acts like a simple multicellular animal, but it's actually just an amoeba swarm.

Swarms have a dark side too though. Because the swarm moves and acts as one, it can quickly become unstable. At low population densities, locusts move about randomly or in small groups. This is controlled by the level of serotonin in each locust, which increases in response to stress. As the density rises they become more and more co-ordinated until, at about 74 locusts per square metre, they stop changing direction altogether and march like an army for hours at a time. Locust swarms begin in response to overcrowding, but because they all travel together, they just make the overcrowding worse, sweeping across farmland like a wildfire and destroying all plant life in their path. It's precisely the co-ordination and synchronisation that can make the swarm so destructive.

## It's a stampede!

What happens when the herding instinct turns nasty?

## The power of the swarm

While individual swarm members do relatively little damage, en masse they have the power to consume everything in their path

Not all swarms are destructive. A swarm of honeybees is essentially peaceful, unless the queen is threatened. And krill drift in the open ocean so the most they can do is eat a lot of plankton.

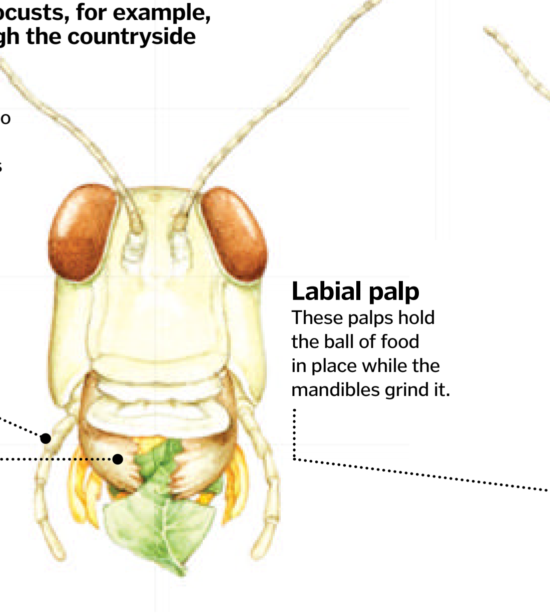
However swarms feeding on land can quickly strip an area bare, simply by virtue of their population density.

Locust swarms, for example, can reach into the billions – with some 380 million insects per square kilometre. Resembling a uniform blanket of locusts, there's no amount of vegetation that can withstand that many mouths for long.

Even when overfeeding isn't a problem, swarms can still cause enormous damage. An animal that might be perfectly innocuous by itself can cause a lot of trouble in large enough numbers. Large flocks of starlings can leave a carpet of droppings up to 30 centimetres (11.8 inches) deep under the trees where they roost. The ammonia compounds in their droppings can quickly reach toxic levels, poisoning grass and other plants if the flock doesn't move on within a few days.

## Jaws of destruction

**Swarms wreak havoc in many different ways. A billion locusts, for example, can chew through the countryside**



### Maxillary palp

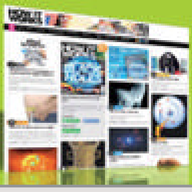
These are sensitive to taste but the locust indiscriminately eats almost all plant matter regardless.

### Labial palp

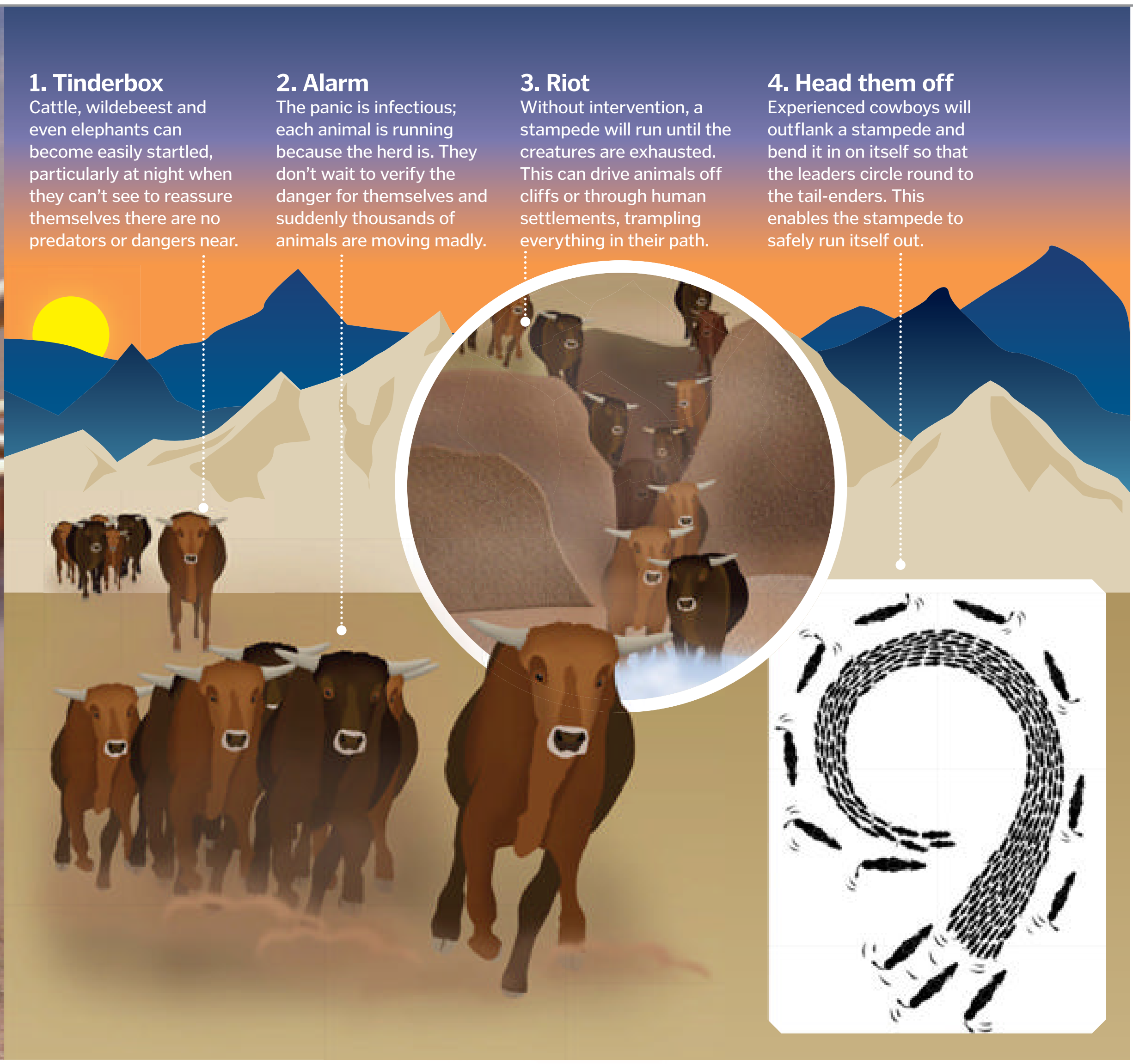
These palps hold the ball of food in place while the mandibles grind it.

### Mandible

The jaws have sharp, serrated edges which can rasp tough plant fibres into shreds.


AMAZING VIDEO! SCAN THE QR CODE FOR A QUICK LINK
Watch an ant colony 'drip' and 'flow' like a fluid

**DID YOU KNOW?** In 1866, a flock of passenger pigeons was recorded at 1.6km (1mi) wide and 483km (300mi) long



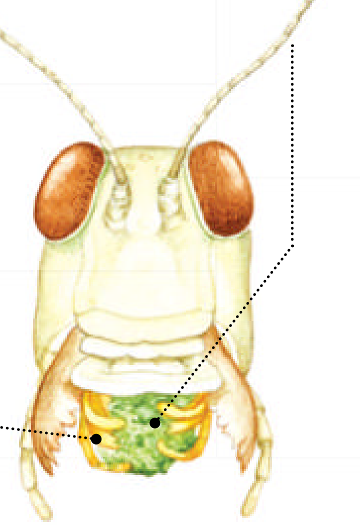
**1. Tinderbox**
Cattle, wildebeest and even elephants can become easily startled, particularly at night when they can't see to reassure themselves there are no predators or dangers near.

**2. Alarm**
The panic is infectious; each animal is running because the herd is. They don't wait to verify the danger for themselves and suddenly thousands of animals are moving madly.

**3. Riot**
Without intervention, a stampede will run until the creatures are exhausted. This can drive animals off cliffs or through human settlements, trampling everything in their path.

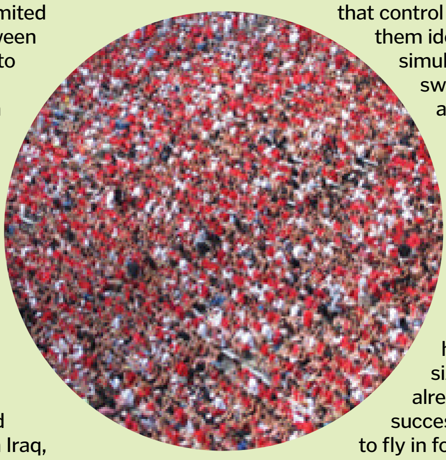
**4. Head them off**
Experienced cowboys will outflank a stampede and bend it in on itself so that the leaders circle round to the tail-enders. This enables the stampede to safely run itself out.

**Wasteful**
Locusts can't digest cellulose, which makes them very inefficient grazers so they have to eat voraciously.



## Swarming humans

Humans can swarm too. When large crowds gather, the limited communication between people causes them to fall back on simple rules: keep moving in the same direction as everyone else; try not to get too squashed up; don't get left behind. If there's a bottleneck or something triggers a panic, the crowd can suddenly become dangerous. In 2005, almost a thousand people died during a stampede in Iraq, when pilgrims marching to the Al-Kadhimiya Mosque in Baghdad became panicked by fears of a suicide bomber. But the science of swarming can also be useful to humans. The simplicity of the rules that control a swarm makes them ideal for robots and simulations. Airports use swarming behaviours adapted from ant colonies to model the flow of passengers through the terminal and to determine the best departure gate to assign to each flight. Elsewhere hovering drones the size of your hand have already been successfully programmed to fly in formation and navigate around obstacles without a human to steer them. In the future, these could be used for military reconnaissance as well as search and rescue missions.



## A perfect swarm

**Animal: Sardine**
**Swarm technique: Shoal**

Every year, young sardines swim from the tip of South Africa, where they spawned, up the coast of Mozambique and into the Indian Ocean. It is thought that cold-water currents trigger this migration. The school can cover an area of 7.1 x 1.5 kilometres (4.4 x 0.9 miles) and 30 metres (98 feet) deep, containing billions of sardines. Up to 18,000 dolphins tag along to feed.

**Animal: Krill**
**Swarm technique: Shoal**

Krill are a shrimp-like crustacean. Antarctic krill have a total biomass twice that of all the humans in the world. Half of this is eaten every year and, to protect themselves, they band together in huge shoals that drift up and down in the water column every day.

**Animal: Wildebeest**
**Swarm technique: Herd**

Wildebeest migrate annually across the Serengeti to follow the rainfall and most nutritious grass. Herds of 1.4 million travel 2,900 kilometres (1,800 miles) per year in a clockwise circle around eastern Africa. Wildebeest are powerful and aggressive, but they still need the additional security of the herd to protect them from hyenas and lions.

© Thinkstock; Getty

> *"Immense tectonic forces have been pulling old continental plates apart and creating new ones"*

# How rift valleys form

## We explore the Great Rift Valley – the largest land-based example found on our planet

For the last 30 million or so years immense tectonic forces in action around north-east Africa have been slowly pulling old continental plates apart and in the process creating new ones.

Earth's rocky outer shell, or lithosphere, floats atop a hotter, denser and more fluid layer called the asthenosphere. The continental lithosphere is about 150 kilometres (93 miles) thick, while the oceanic lithosphere beneath our seas is thinner, 100 kilometres (60 miles) at its thickest. This brittle surface layer consists of 12 major tectonic plates and numerous smaller ones, all of which are in constant motion due to convection currents within the Earth's mantle. The plates are moving very slowly but surely at roughly five to ten centimetres (two to four inches) per year. This movement stretches and squeezes the lithosphere in all directions. At their boundaries, or faults, these plates interact – either converging (colliding), diverging (moving apart) or slipping past each other.

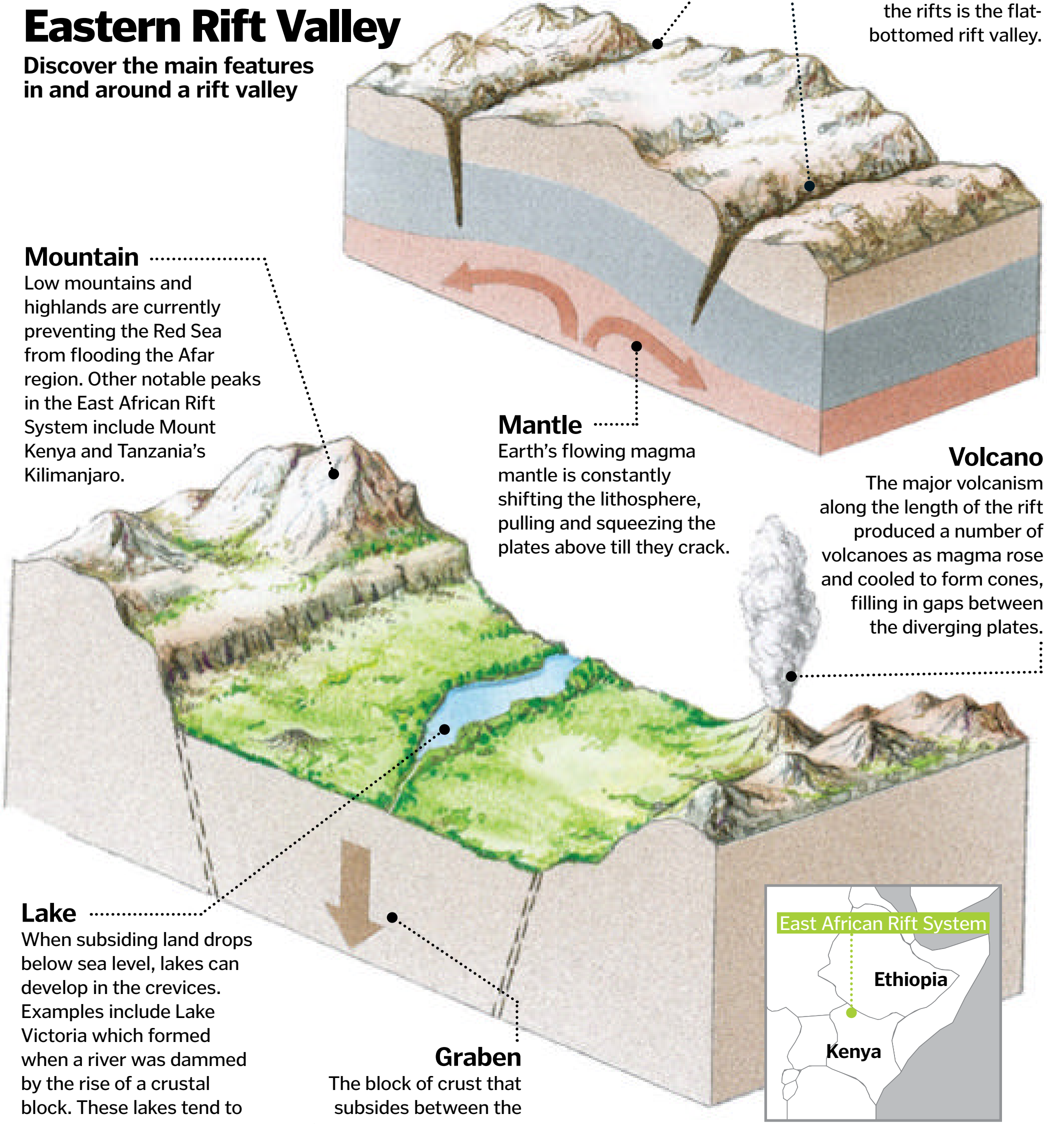
In the so-called East African Rift System (EARS) region there are three large diverging plates: the Arabian Plate and Africa's Somalian and Nubian protoplates. The intersection of these plates – known as the Afar Triangle or Afar Depression – is located at the mouth of the Red Sea. The Eastern Rift Valley (which is more commonly referred to as the Great Rift Valley) is a zone of tectonic subsidence that extends the full length of the EARS.

A rift valley is the long, narrow, flat-bottomed trough of land created when a block of Earth's lithospheric crust drops into the space that's left when two divergent tectonic plates drift apart. They can be anything from ten kilometres (six miles) to several hundred kilometres wide, with a roughly symmetrical cross-section. The entire East African Rift System, meanwhile, extends some 6,400 kilometres (4,000 miles) north to south from Syria in south-west Asia, down through the Red Sea and along the African coast all the way to Mozambique in the south-east of the continent.

If this rift continues the valley could sink low enough for the Gulf of Aden to flood the region, turning the Horn of Africa into an island.

### Eastern Rift Valley

**Discover the main features in and around a rift valley**



**Rifts**
As two tectonic plates diverge (ie move apart) cracks called rifts appear. The trough in between the rifts is the flat-bottomed rift valley.

**Mountain**
Low mountains and highlands are currently preventing the Red Sea from flooding the Afar region. Other notable peaks in the East African Rift System include Mount Kenya and Tanzania's Kilimanjaro.

**Mantle**
Earth's flowing magma mantle is constantly shifting the lithosphere, pulling and squeezing the plates above till they crack.

**Volcano**
The major volcanism along the length of the rift produced a number of volcanoes as magma rose and cooled to form cones, filling in gaps between the diverging plates.

**Lake**
When subsiding land drops below sea level, lakes can develop in the crevices. Examples include Lake Victoria which formed when a river was dammed by the rise of a crustal block. These lakes tend to be large, deep and ancient.

**Graben**
The block of crust that subsides between the rifts is known as a graben.

### The cradle of humanity?

North-east Africa's Afar region is a site of scientific interest as some of the biggest palaeoanthropological breakthroughs have arisen there. This includes the discovery of the 3.2-million-year-old fossilised remains of a female nicknamed Lucy. The rift's history holds the answers to many questions about our ancestors' evolution and how early humans developed the intelligence to walk on two feet and adapt to major climate changes. Tanzania's Olduvai Gorge in particular has unearthed over 60 hominids (early humans). The fossil deposits in this steep-sided, 40-kilometre (25-mile)-long gorge saw it become a UNESCO World Heritage Site back in 1979. No other location has revealed ancient remnants so closely connected to their environment.

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> "Estuaries are at the mercy of the tides, which flush the sandy, muddy expanse with saltwater twice a day"

# How do estuaries work?

Take a look at the dynamic and diverse environment at the mouth of a river

Every river that meanders through the countryside will eventually reach the sea. At the river's mouth, this partially enclosed frontier of fresh river water and briny seawater essentially defines an estuary, which is one of the most productive ecosystems on Earth.

The majority of estuaries around the world today were formed during the Holocene period (that is, approximately 12,000 years ago) as rising sea levels flooded river valleys. However, estuaries can come about by other means too, such as glaciation or oceanographic and tectonic processes.

The brown, boggy expanse of mud that is so typical of these areas is the product of sand and silt washed down and deposited by the river. Decaying matter is washed into the estuary too, making it rich in nutrients and also lending it that distinctive low-tide odour. In the case of much larger rivers, this deposition of sediment will form a delta.

It's the transport of nutrients and biological matter washed from land to sea and back that makes an estuary so productive. But this isn't just for flora and fauna, as estuaries also provide sheltered natural harbours that buzz with human life too.

Estuaries are at the mercy of the tides, which flush the sandy, muddy expanse with saltwater twice a day. The extent of this mixing is defined by the cycle of the tides and directly affects an estuary's unique characteristics. These areas can range from well-mixed environments to a heavily stratified basin of contrasting chemical properties. Regardless of type, however, every estuary is teeming with life, offering food and shelter to organisms ranging from microbes through to top predators.

## Life in the mud

With nutrients readily available in the sediment and water, all kinds of life are drawn to these productive biological melting pots.

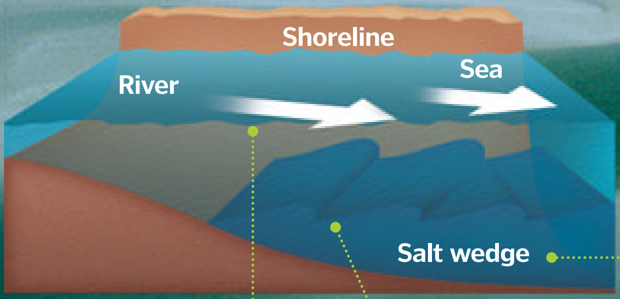
The microbial community thrives on the silt and sediment washed down from the riverbed and the mud flats are packed with invertebrates, providing food for hundreds of bird species. Algal growth blooms and filter feeders, such as mussels, are attracted to live in the oxygenated flats. Estuaries are also home to plenty of fish and crustaceans such as mullet, bass and spider crabs. These in turn are the perfect meal for predators like seals and herons.

Estuaries serve as vital nursery grounds. Many young species exist here, such as salmon smolts (a stage in between fry and adult), which feed to fatten up before venturing into the open ocean.

## Types of estuary

**While they may all appear very different, most estuaries fit in to four main categories…**

### Salt-wedge estuary

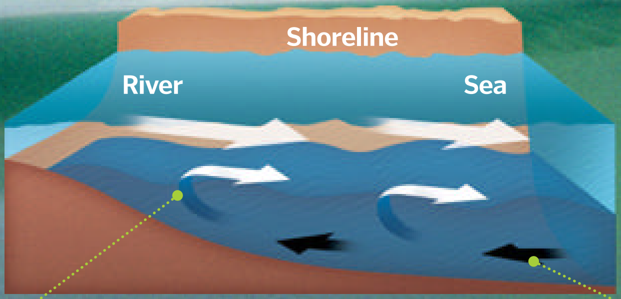


**Seawater properties**
Seawater solutes include sodium and chloride. Dissolved substances make it denser than freshwater, so the wedge sinks to the bottom of the estuary.

**River dominates**
A strong influx of river water and low tidal influence results in limited mixing of the two water types.

**Stratification**
The seawater sits underneath the fresh river water, resulting in a visible briny 'wedge' – known as a halocline – in the water column.

### Partially mixed estuary



**Balanced flow**
Salinity levels fluctuate and there is some stratification, but the halocline is not as pronounced as some vertical mixing occurs.

**Changing profiles**
Each day the salinity profile will progress through drastic changes that native species must adapt to in order to survive.

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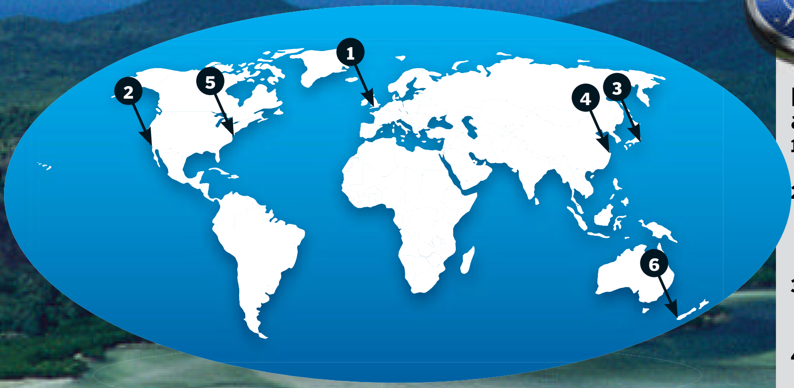
### WORLD'S BIGGEST ESTUARY

Many think the St Lawrence River Estuary in Canada is Earth's largest. 12 million litres (3.2 million gallons) of water pour into the Gulf of St Lawrence per second!

**DID YOU KNOW?** *Birds are drawn to feed at estuaries as a cubic metre of mud contains the calorific value of 14 Mars bars!*

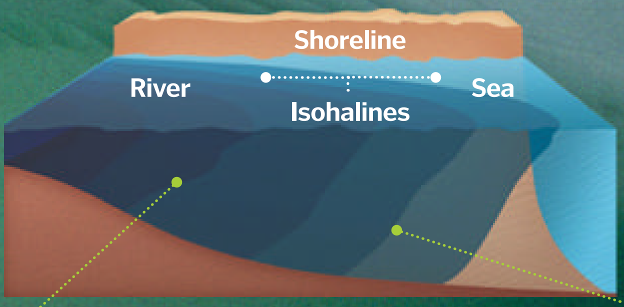


## ON THE MAP

### Major estuaries across the globe

1. Severn Estuary: River Severn, UK
2. San Francisco Bay: Sacramento and San Joaquin Rivers, San Francisco, CA, USA
3. Tokyo Bay: Sumida and Arakawa Rivers, Tokyo, Japan
4. Yangtze River Estuary: Shanghai, China
5. Chesapeake Bay: Susquehanna, Chester, Potomac, James Rivers (plus many others), VA, USA
6. Doubtful Sound (fjord): Fiordland, New Zealand

### Vertically homogenous estuary

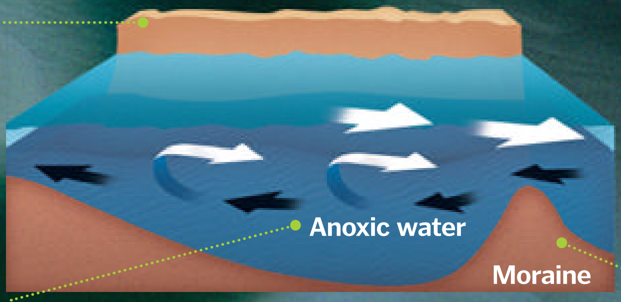


**Salinity gradient**
Salinity is evenly distributed throughout the estuary; only at the uppermost reaches of the tide is a salinity gradient apparent.

**Lateral mixing**
Tidal mixing dominates here. The force of the sea mixes the two water types so that salt and freshwater are combined evenly.

### Fjord estuary

**Glaciation**
Fjords are flooded valleys, characterised by steep, rocky banks and very deep river bottoms that were carved out by glaciers.



**Anoxic layer**
Deep fjords often have a layer of anoxic (low-oxygen) water near the bottom, with very different chemical and biological properties.

**Sill**
At the mouth of the fjord is the edge (sill) of the glacial moraine – a mound of rocks and gravel pushed ahead and deposited by a glacier.

© Corbis

*"A kingfisher can home in on a fish and watch from overhead by beating its wings eight times a second"*

# How do kingfishers hunt?

Discover how these skilful dive-bombers swoop down and seize their lunch in style

The kingfisher's diet chiefly consists of small fish like minnows

While some of Earth's creatures – the dragonfly, for instance – don't particularly live up to their names, the kingfisher most certainly does. Indeed, this small but skilled riverbank predator is capable of some of the most spectacular aerial manoeuvres in the animal kingdom.

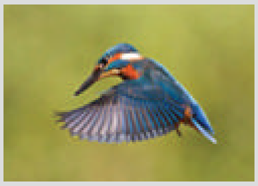
The largest bird capable of hovering mid-flight, the kingfisher can boast a number of techniques for locating and intercepting the unsuspecting fish below.

From its vantage point over a river or stream, the bird spies its victim and looks on with interest. From as high as ten metres (32 feet) above the waterway a kingfisher can home in on a single fish and then watch silently overhead by rapidly beating its wings as fast as eight times a second. In order to remain in sync with the fish's exact co-ordinates the kingfisher must keep its head almost entirely motionless, letting the wings and counterbalancing tail do all the work.

When ready the kingfisher strikes, performing a controlled vertical dive to ensure its dart-like bill is the first thing to enter the water. Though sharp and streamlined, it still generates shockwaves through the water that can startle a fish so speed is of the essence. Indeed, the difference between the kingfisher catching its prize or not can come down to a matter of a mere 50th of a second! If the fish reacts within that time it's likely to dart out of harm's way and the hunter will go hungry.

If successful, the kingfisher then swoops off, fish in beak, back to its favourite vantage point – usually a riverbank perch. There it stuns the fish by hitting it against a hard surface before flipping it headfirst into its gullet. ✤

## The statistics...



### *Common kingfisher*

**Type:** Bird

**Binomial:** Alcedo atthis

**Diet:** Carnivore, eg fish, crustaceans, aquatic insects

**Average life span in the wild:** 7 years

**Length:** 16cm (6.3in)

**Wing span:** 25cm (9.8in)

**Weight:** 25-40g (0.9-1.4oz)

Although kingfisher plumage appears a brilliant blue-green colour its feather pigment is actually dark brown. The blue colour comes from iridescence caused by the refraction of light between its layers of feathers

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> "Hydrothermal vents are similar to hot springs on land, but sit around 2,100m (7,000ft) beneath the ocean"

# Hydrothermal vents

## Find out how these oceanic hot springs form and why sealife depends on them

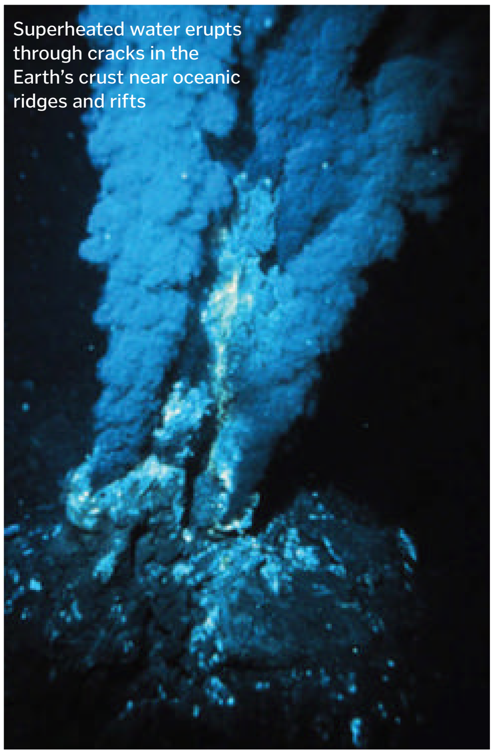
The deep ocean is one of the harshest places to live on our planet – cold, dark and with pressures up to 250 times greater than on land. When scientists discovered the first hydrothermal vent in 1977, they were amazed to see heaps of clamshells clinging to it and large colonies of shrimp.

Volcanic, or hydrothermal, vents (also called smokers) are similar to hot springs on land, but sit around 2,100 metres (7,000 feet) beneath the ocean surface. Superheated water spews out of cracks in the seabed forming plumes of mineral particles that look like smoke. Fragile chimneys of minerals up to ten metres (33 feet) high form around the plumes and can grow upwards at 30 centimetres (12 inches) a day.

Temperatures vary between two degrees Celsius (35.6 degrees Fahrenheit) in the deep ocean to above boiling point around the vents. The water is heated by molten rock close to the seabed. Cracks and hot rocks are found at rifts where vast tectonic plates that make up Earth's crust are slowly moving apart. New ocean crust is created in the gaps between plates.

No one knows how many vents exist. The deep ocean is largely unexplored by humans – the first vents were photographed by unmanned research submersibles. The vents cool after a few years or decades as new ocean crust moves outwards from the mid-ocean ridges by 6-18 centimetres (2.4-7 inches) per year. New vents are quickly colonised by bacteria, which live in deep-sea rocks and water in small numbers.

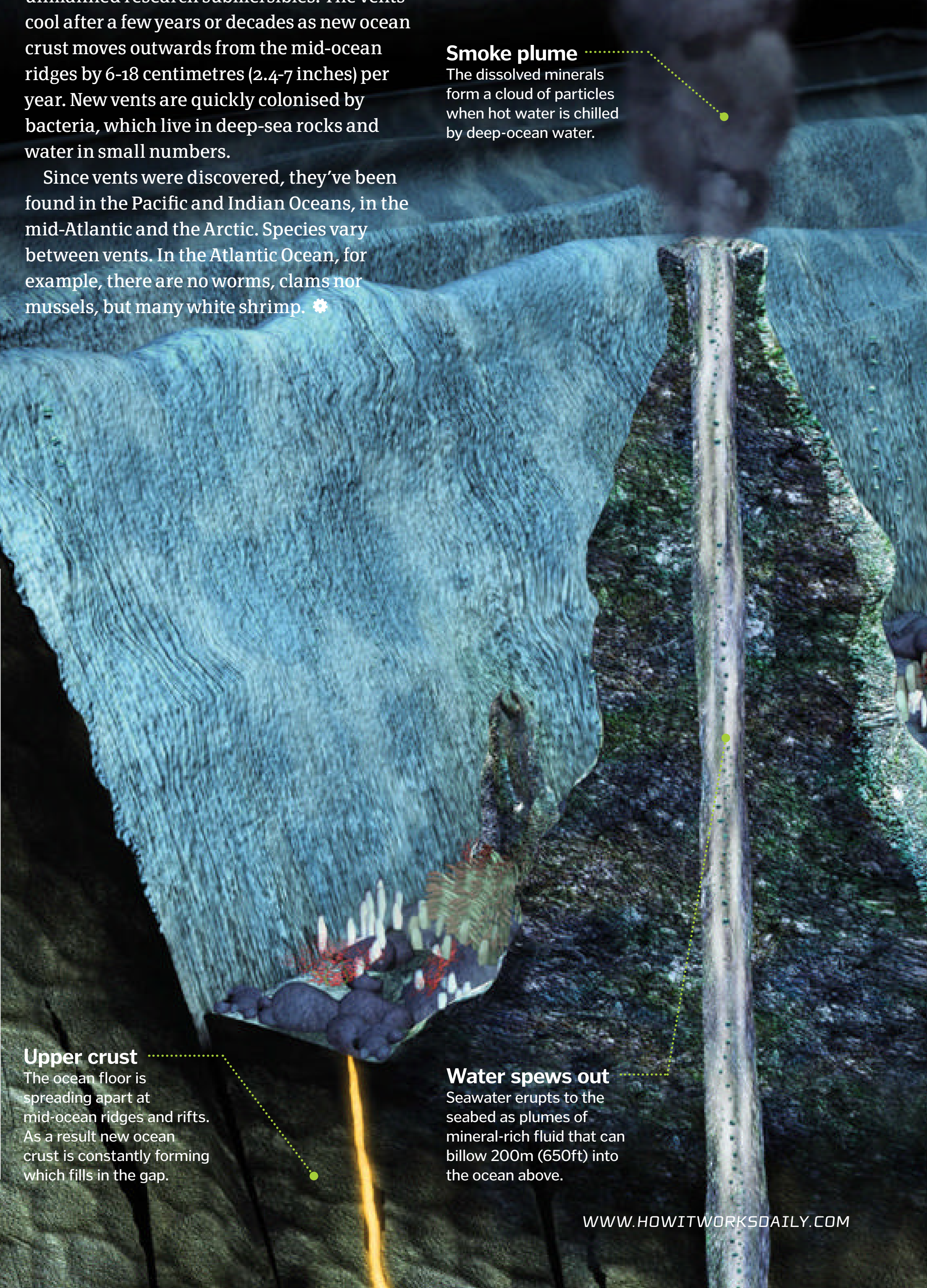
Since vents were discovered, they've been found in the Pacific and Indian Oceans, in the mid-Atlantic and the Arctic. Species vary between vents. In the Atlantic Ocean, for example, there are no worms, clams nor mussels, but many white shrimp.



Superheated water erupts through cracks in the Earth's crust near oceanic ridges and rifts

## How smokers work

**Learn why volcanic vents create chimneys and colourful smoke in the ocean depths**



**Smoke plume** The dissolved minerals form a cloud of particles when hot water is chilled by deep-ocean water.

**Upper crust** The ocean floor is spreading apart at mid-ocean ridges and rifts. As a result new ocean crust is constantly forming which fills in the gap.

**Water spews out** Seawater erupts to the seabed as plumes of mineral-rich fluid that can billow 200m (650ft) into the ocean above.

## 5 TOP FACTS

VENT LIFE

**Vent tube worm**

**1** These bizarre red-and-white worms can be two metres (six feet) tall and have no mouth or stomach. They rely on bacteria living inside them to convert chemicals into food.

**Pompeii worm**

**2** These bristle-covered worms can survive in hotter conditions than any other animal. They live inside vent chimneys, where it's over 80 degrees Celsius (176 degrees Fahrenheit)!

**Vent crab**

**3** Adult vent crabs have eyesight similar to military night-vision goggles to help them see at ocean depths of 2.7 kilometres (1.7 miles). They are the top predators around vents.

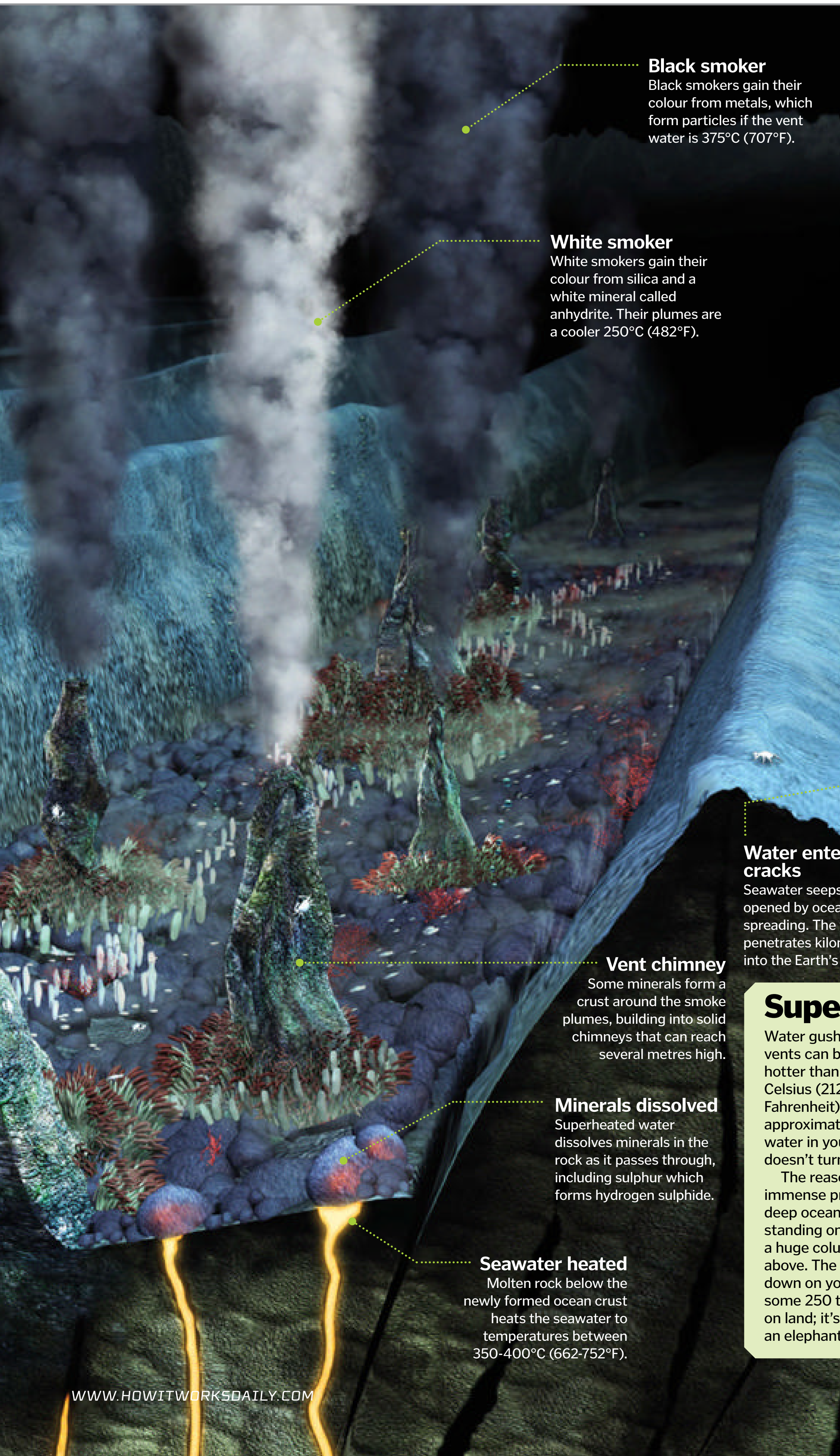
**Vent shrimp**

**4** These blind invertebrates have simple light detectors on their backs instead of eyes, which may work like infrared heat vision to help them spot glowing vents in the gloom.

**Scaly-foot gastropod**

**5** The metal scales protecting these snails from crab attack are unique – other snails have soft, slimy feet. Their body armour could inspire designs of motorcycles or flak jackets.

**DID YOU KNOW?** There may be hydrothermal vents that could support alien life beneath an ocean on Jupiter's moon Europa



**Black smoker**
Black smokers gain their colour from metals, which form particles if the vent water is 375°C (707°F).

**White smoker**
White smokers gain their colour from silica and a white mineral called anhydrite. Their plumes are a cooler 250°C (482°F).

**Water enters cracks**
Seawater seeps into cracks opened by ocean floor spreading. The water penetrates kilometres deep into the Earth's crust.

**Vent chimney**
Some minerals form a crust around the smoke plumes, building into solid chimneys that can reach several metres high.

**Minerals dissolved**
Superheated water dissolves minerals in the rock as it passes through, including sulphur which forms hydrogen sulphide.

**Seawater heated**
Molten rock below the newly formed ocean crust heats the seawater to temperatures between 350-400°C (662-752°F).

## Living without sunlight

The first life able to exist without energy from sunlight was discovered around a black smoker vent. Before then, scientists believed life in the dark deep ocean survived by eating food scraps that had fallen from shallower waters.

More than 300 species of shrimp, clams, predatory anemones and others live around vents – many unique – with around 35 new species discovered each year. All rely for food on mats of white bacteria, which use poisonous hydrogen sulphide from vent water as fuel to convert carbon dioxide and water into edible carbohydrates. Some species, such as vent worms, have bacteria living in their bodies. These bacteria take the place of plants on the Earth's surface. When the vent cools, tiny organisms can also eat the iron and sulphur inside the chimneys.

## Superheating explained

Water gushing from volcanic vents can be four times hotter than 100 degrees Celsius (212 degrees Fahrenheit) – the approximate boiling point of water in your kettle. Yet it doesn't turn into steam...

The reason for this is the immense pressure in the deep ocean. Imagine you're standing on the seabed with a huge column of water above. The ocean weighs down on you with a pressure some 250 times greater than on land; it's similar to having an elephant stand on your big toe! These high pressures squeeze water in volcanic vents, stopping it expanding when heated. When liquid water boils into steam, molecules that were close together absorb enough heat energy to fly off in different directions. But these huge pressures prevent water molecules flying around as steam – they can't get far enough before hitting another moving molecule.

Superheated water can enter rock cracks like steam, but is as effective as water at dissolving minerals.

© Getty; NOAA; Dr Bob Embley/OAR/NURP

# 50 AMAZING FACTS ABOUT SCIENCE

From Earth's geology to the complex workings of the human body and on to the farthest reaches of outer space, HIW presents some fascinating insights that will blow your mind

Like you, we love learning about science. And luckily, every day is a school day on **How It Works** magazine because there's *always* something new and remarkable to discover about the world we live in. From the very moment we're born we begin to take in information about the planet around us, and as we get older it becomes only natural to grow curious and start asking questions like how and why.

So not only does this special **How It Works** feature reveal 50 of the most amazing science facts, but it also explains the equally amazing principles that lie behind them, helping you to get a handle on *why* each fact works the way it does.

When we announced on Twitter we were running a feature about incredible scientific trivia, our feed was immediately inundated by readers keen to share their favourite nuggets of information. And after sifting through the hundreds of fantastic entries that came in from all over the world – and doing some of our own research – we selected the best of the bunch.

Topics cover everything from the origins of the cosmos to how the cells in our bodies work, so over these eight jam-packed pages, you will discover a wealth of mindblowing knowledge to astound you and everyone you know as we explain the science behind some of the universe's most amazing facts.

## HEAD 2 HEAD

**SUPERSTARS**

**1. HOTTEST**

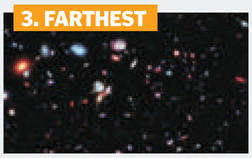
### Bug Nebula

The hottest star in the Milky Way is at the centre of the Bug Nebula 3,500 light years away. Its surface temperature is 35 times hotter than the Sun's.

**2. OLDEST**

### Caffau's star

A star with a very strange composition (full name SDSS J102915+172927) at the edge of our galaxy is suspected to be more than 13 billion years old.

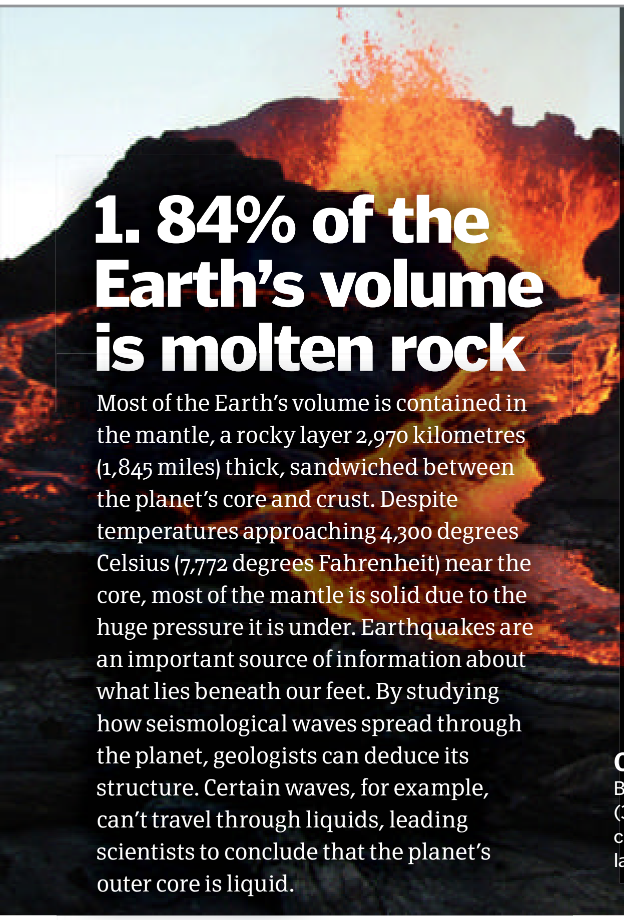


**3. FARTHEST**

### Big Bang galaxies

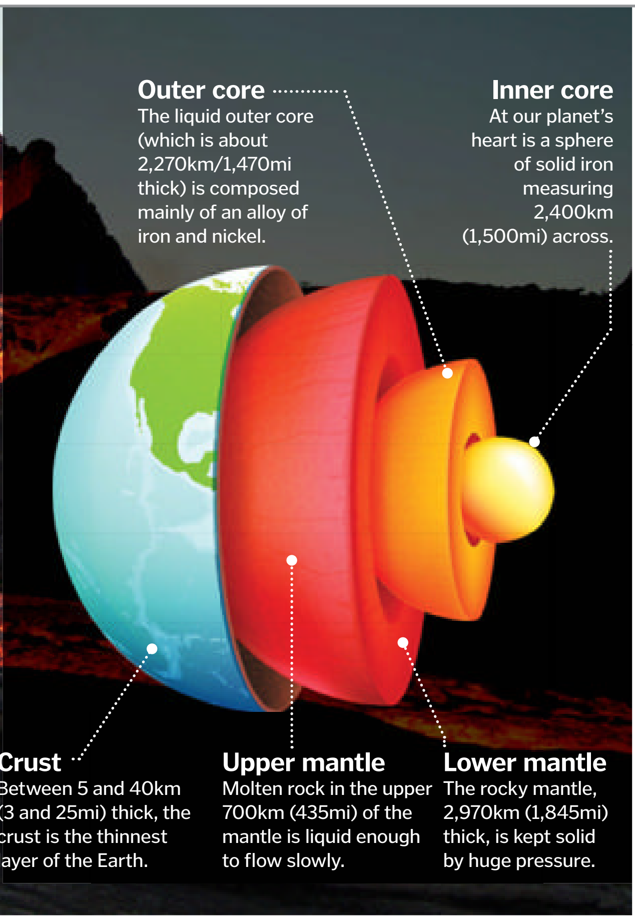
The most distant stars are over 13 billion light years away, in galaxies that formed shortly after the Big Bang.

**DID YOU KNOW?** *The oldest living thing in the world is a 200,000-year-old patch of seagrass off Formentera, Spain*



# 1. 84% of the Earth's volume is molten rock

Most of the Earth's volume is contained in the mantle, a rocky layer 2,970 kilometres (1,845 miles) thick, sandwiched between the planet's core and crust. Despite temperatures approaching 4,300 degrees Celsius (7,772 degrees Fahrenheit) near the core, most of the mantle is solid due to the huge pressure it is under. Earthquakes are an important source of information about what lies beneath our feet. By studying how seismological waves spread through the planet, geologists can deduce its structure. Certain waves, for example, can't travel through liquids, leading scientists to conclude that the planet's outer core is liquid.



**Outer core**
The liquid outer core (which is about 2,270km/1,470mi thick) is composed mainly of an alloy of iron and nickel.

**Inner core**
At our planet's heart is a sphere of solid iron measuring 2,400km (1,500mi) across.

**Crust**
Between 5 and 40km (3 and 25mi) thick, the crust is the thinnest layer of the Earth.

**Upper mantle**
Molten rock in the upper 700km (435mi) of the mantle is liquid enough to flow slowly.

**Lower mantle**
The rocky mantle, 2,970km (1,845mi) thick, is kept solid by huge pressure.

## 2. You can't see a laser beam in space

A laser is a highly focused beam of light. So focused, in fact, that none of its photons deviate from their path and enter your eyes, unless they are reflected by particles of dust. In the almost-perfect vacuum of space there is no matter so lasers are invisible, despite what many a science-fiction film might suggest.

# 3. Babies have around 100 more bones than adults

Babies have about 300 bones at birth, with cartilage between many of them. This extra flexibility helps them pass through the birth canal and also allows for rapid growth. With age, many of the bones fuse, leaving 206 bones that make up an average adult skeleton.

# 4. The Eiffel Tower can be 15cm taller during the summer

When a substance is heated up, its particles move more and it takes up a larger volume – this is known as thermal expansion. Conversely, a drop in temperature causes it to contract again. The mercury level inside a thermometer, for example, rises and falls as the mercury's volume changes with the ambient temperature. This effect is most dramatic in gases but occurs in liquids and solids such as iron too. For this reason large structures such as bridges are built with expansion joints which allow them some leeway to expand and contract without causing any damage.

# 5. Butterflies taste with their feet

Butterflies' hind feet, technically known as tarsi, are covered in chemoreceptors – tiny organs which allow them to taste something just by standing on it. This anatomical quirk enables a female butterfly to pick a leaf suitable for her caterpillars to eat before she lays her eggs. More generally, once it has spotted a tasty-looking flower, a butterfly can sample the goods quickly before settling down to feed.

## 6 Muscles can remember

The first time you perform an action – tying shoelaces, for example, it feels awkward, but with enough repetition it becomes second nature. The brain stores sets of motor instructions, allowing such tasks to be executed without conscious effort. Muscle memory is retained for a long time, so skills like driving a car are rarely completely lost.

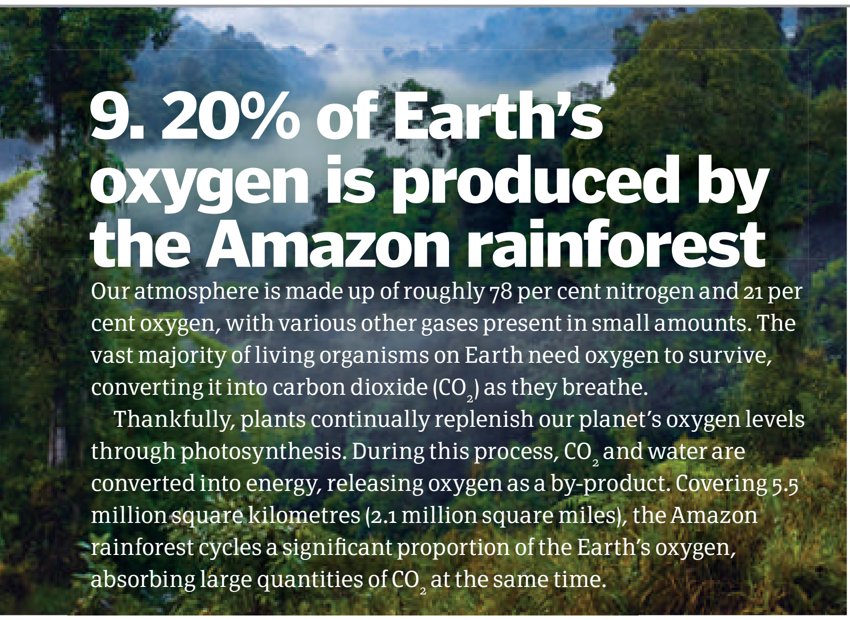
## 7 Pumice is the only rock that can float

Pumice is formed when hot, highly pressurised lava is ejected from a volcano. The sudden drop in pressure and rapid cooling trap bubbles of gas in the rock, giving it a lower density than water.

## 8 Only diamond can cut diamond

Diamonds are carbon, with each atom bound with strong covalent bonds to four neighbours in a rigid lattice. Diamonds tend to grow in octahedral shapes, and some of the octahedron's faces are weaker than others. Jewellers can cut along these planes with special tools coated in diamond dust.

> "Nociceptors are found throughout the body, particularly just under the skin, but are absent from the brain"



## 9. 20% of Earth's oxygen is produced by the Amazon rainforest

Our atmosphere is made up of roughly 78 per cent nitrogen and 21 per cent oxygen, with various other gases present in small amounts. The vast majority of living organisms on Earth need oxygen to survive, converting it into carbon dioxide ($CO_2$) as they breathe.

Thankfully, plants continually replenish our planet's oxygen levels through photosynthesis. During this process, $CO_2$ and water are converted into energy, releasing oxygen as a by-product. Covering 5.5 million square kilometres (2.1 million square miles), the Amazon rainforest cycles a significant proportion of the Earth's oxygen, absorbing large quantities of $CO_2$ at the same time.

## 10. Dynamite may contain nuts

Dynamite's explosive ingredient is nitroglycerin, absorbed onto clay particles for stability. Nitroglycerin is made with glycerol, which can be extracted from peanuts. This said, there are other ways of producing nitroglycerin as well.

## 11. The brain does not feel pain

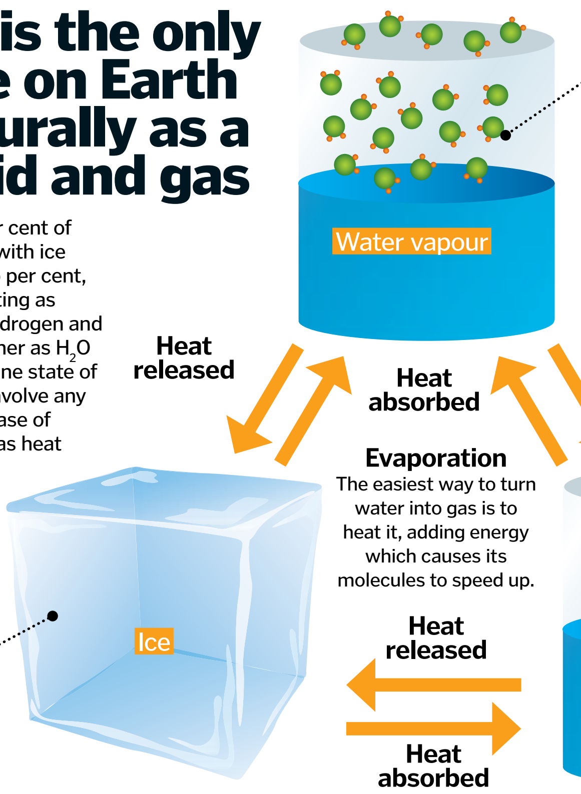
We feel pain thanks to nociceptors – sensory receptors which send signals to the spinal cord and brain, alerting us to danger and enabling us to react. Nociceptors are found throughout the body, particularly just under the skin, but they are entirely absent from one place: the brain. When you have a headache, it isn't actually your brain that's suffering but the tissues around it which include muscles, sinuses and the membranes that protect the organ.

## 12. Some metals are so reactive that they explode on contact with water

There are certain metals – including potassium, sodium, lithium, rubidium and caesium – that are so reactive that they oxidise (or tarnish) instantly when exposed to air. They can even produce explosions when dropped in water! All elements strive to be chemically stable – in other words, to have a full outer electron shell. To achieve this, metals tend to shed electrons. The alkali metals have only one electron on their outer shell, making them ultra-keen to pass on this unwanted passenger to another element via bonding. As a result they form compounds with other elements so readily that they don't exist independently in nature.

## 13. Water is the only substance on Earth found naturally as a solid, liquid and gas

At any one time, over 98 per cent of our planet's water is liquid, with ice making up a little under two per cent, and only a tiny fraction existing as vapour. Water is made of hydrogen and oxygen atoms, bound together as $H_2O$ molecules. Changing from one state of matter to another doesn't involve any chemical changes but is a case of adding or removing energy as heat or pressure, affecting the behaviour of the $H_2O$. In liquid water, molecules move freely. Cool it down and, as they lose energy, the molecules slow down until the point where they form a rigid structure: ice.

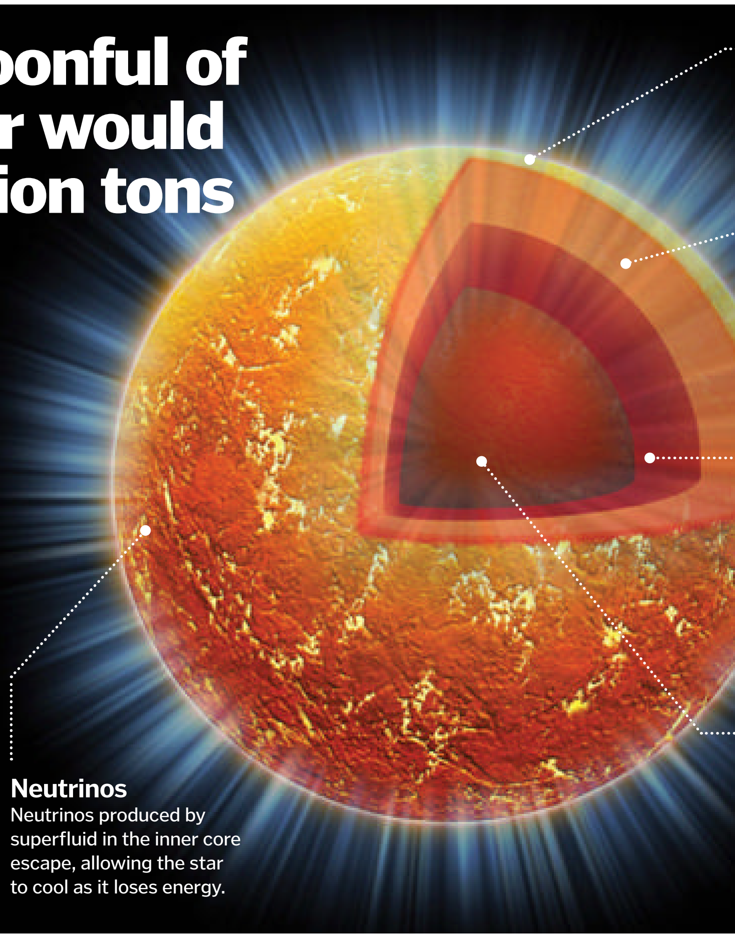


**Solid**
In ice, the $H_2O$ molecules have very little energy and lock into a rigid lattice.

**Evaporation**
The easiest way to turn water into gas is to heat it, adding energy which causes its molecules to speed up.

## 14. A teaspoonful of neutron star would weigh 6 billion tons

A neutron star is the remnants of a massive star that has run out of fuel. The dying star explodes in a supernova while its core collapses in on itself due to gravity, forming a super-dense neutron star. Astronomers measure the mind-bogglingly large masses of stars or galaxies in solar masses, with one solar mass equal to the Sun's mass (that is, 2 x $10^{30}$ kilograms/4.4 x $10^{30}$ pounds). Typical neutron stars have a mass of up to three solar masses, which is crammed into a sphere with a radius of approximately ten kilometres (6.2 miles) – resulting in some of the densest matter in the known universe.



**Neutrinos**
Neutrinos produced by superfluid in the inner core escape, allowing the star to cool as it loses energy.

**STRANGE BUT TRUE**
**TWIST IN THE TAIL**

**Stegosaurus used its spinal and tail plates for what?**

**A** Self-defence **B** Attracting mates **C** Keeping cool

**Answer:**
Strangely, despite their sharp, large and impressive appearance, the Stegosaurus's plates were merely used for regulating internal body temperature. The plates contained blood vessels and acted like radiators, releasing excess body heat when needed.

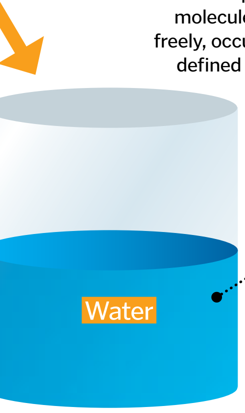
**DID YOU KNOW?** *Absolute zero is the lowest possible temperature, although it's theoretically impossible to achieve it*

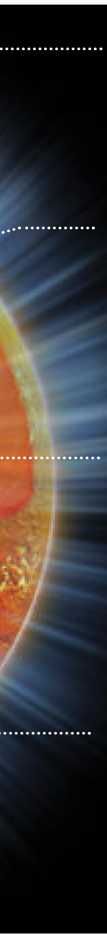
**Gas**
Water vapour molecules possess lots of energy, bouncing off one another and increasing the gas's volume.

**Condensation**
Cooling water vapour down releases energy, allowing the water molecules to slow down and form a liquid.

**Heat released**

**Liquid**
As a liquid, $H_2O$ molecules move freely, occupying a defined volume.





**Outer crust**
The rigid crust is made up of a lattice of iron nuclei, which are bathed in electrons.

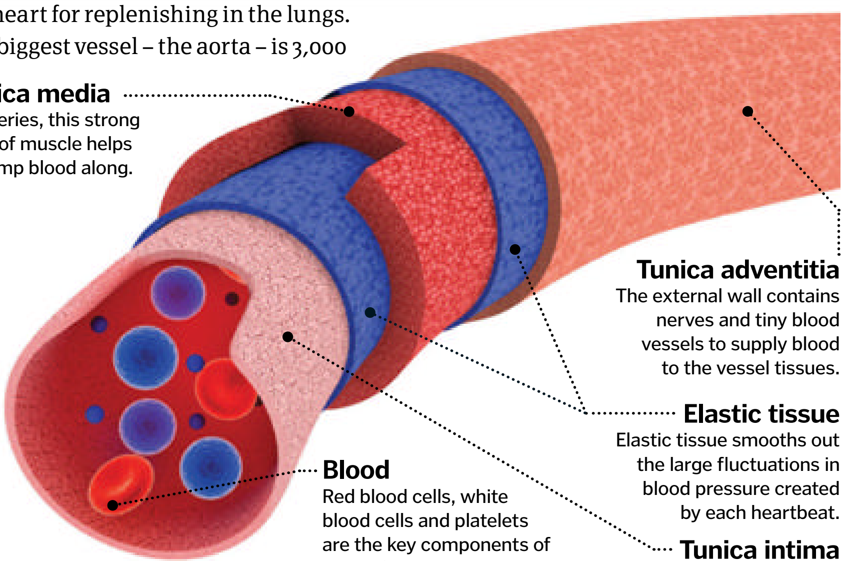
**Inner crust**
The crushing pressure forces protons and electrons together, forming neutrons which leak out of the nuclei.

**Outer core**
Little is known about the neutron star's core, but it is thought neutrons here form a superfluid – a strange frictionless state of matter.

**Inner core**
At the star's heart, density peaks at around 4 x $10^{14}$ grams/$cm^3$.

## 15. Your blood vessels would circle the world two and a half times if laid end to end

Blood vessels are hollow tubes that carry blood around your body, delivering vital oxygen, nutrients and water. Arteries carry oxygen-rich blood away from the heart, minute capillaries deliver it to the tissues, while veins transport the deoxygenated blood and waste back to the heart for replenishing in the lungs. The biggest vessel – the aorta – is 3,000 times wider than the smallest capillaries, where red blood cells (which carry the oxygen) have to line up in single file to squeeze through. These red blood cells are unusual in that they have no nucleus, meaning they can dedicate even more space to transporting oxygen.



**Tunica media**
In arteries, this strong layer of muscle helps to pump blood along.

**Tunica adventitia**
The external wall contains nerves and tiny blood vessels to supply blood to the vessel tissues.

**Elastic tissue**
Elastic tissue smooths out the large fluctuations in blood pressure created by each heartbeat.

**Blood**
Red blood cells, white blood cells and platelets are the key components of blood, floating in plasma.

**Tunica intima**
The innermost layer of the vessel is made of collagen and smooth muscle, allowing blood to flow unhindered.

## 16. Chalk is made of trillions of microscopic plankton fossils

Tiny single-celled algae called coccolithophores have lived in Earth's oceans for 200 million years. Unlike any other marine plant, they surround themselves with minuscule plates of calcite (coccoliths). Just under 100 million years ago, conditions were just right for coccolithophores to accumulate in a thick layer coating ocean floors in a white ooze. As further sediment built up on top, the pressure compressed the coccoliths to form rock, creating chalk deposits such as the white cliffs of Dover. Coccolithophores are just one of many prehistoric species that have been immortalised in fossil form, but how do we know how old they are? Over time, rock forms in horizontal layers, leaving older rocks at the bottom and younger rocks near the top. By studying the type of rock in which a fossil is found palaeontologists can roughly guess its age. Carbon dating estimates a fossil's age more precisely, based on the rate of decay of radioactive elements such as carbon-14.

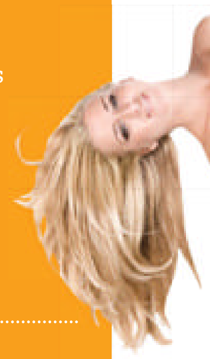
## 17. In 2.3 billion years it will be too hot for life to exist on Earth

Over the coming hundreds of millions of years, the Sun will continue to get progressively brighter and hotter. In just over 2 billion years, temperatures will be high enough to evaporate our oceans, making life on Earth impossible. Our planet will become a vast desert similar to Mars today. As it expands into a red giant in the following few billion years, scientists predict that the Sun will finally engulf Earth altogether, spelling the definite end for our planet.

## 18 The 9m-long Stegosaurus had a brain the size of a walnut

This peaceful prehistoric herbivore was certainly big but not very clever. Animal intelligence is often estimated using the encephalisation quotient, or EQ, which compares an animal's brain weight to that of other 'typical' similarly sized creatures. Cold-blooded animals usually have lower EQs than warm-blooded mammals, but Stegosaurus still lags in the dino smarts rankings, with smaller carnivores like Velociraptor occupying the top spots.

## 19 Blonds have more hair



The average blond has 140,000 hairs on their head, compared to 110,000 for brunettes and 90,000 for redheads. Blond hair tends to be finer than other hair colours.

## 20 Every day a human produces 300 billion new cells

Your body renews itself continually as old cells are discarded and new ones created. On average, cells live for eight years. Some, however, last just a few days, whereas others (like brain cells) are with you for life.

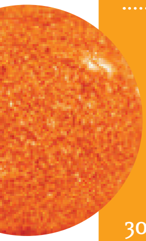
## 21 An electric eel can produce 650 volts

Electric eels get their spark from specialised cells called electrocytes. These create a negative charge of about -0.1 volts by controlling the flow of ions across cell membranes. When an eel spots its prey, these thousands of tiny batteries join forces to deliver a mind-numbing shock.

> *"Tectonic plates are in constant motion, propelled by currents in the Earth's upper mantle"*

## 22 E=mc²

Einstein's famous equation states that energy (E) and matter (represented by m for mass) are one and the same (c is the speed of light). So matter can be viewed as an extremely concentrated form of energy. This principle is demonstrated in nuclear fission and fusion reactions which transform mass into vast amounts of energy.



## 23 It takes 8 minutes, 19 seconds for light to travel from the Sun to the Earth

In space, light travels at 300,000 kilometres (186,000 miles) per second. Even at this breakneck speed, covering the 150 million odd kilometres (93 million miles) between us and the Sun takes a considerable time. And eight minutes is still very little compared to the five and a half hours it takes for the Sun's light to reach Pluto.

## 24 Every living thing has at least one parasite living on/in it

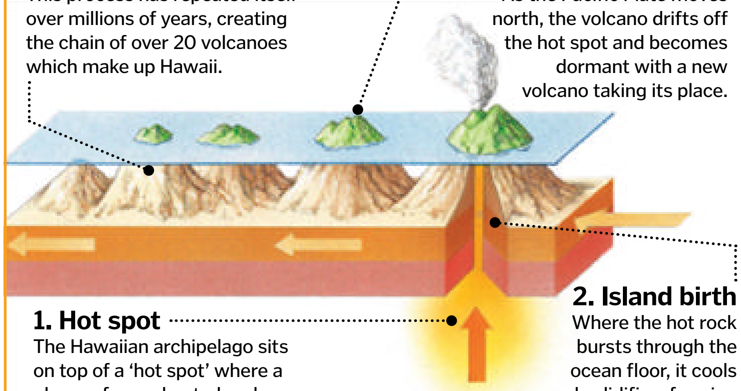
The majority of species on Earth are parasites, including everything from cuckoos to intestinal worms, bacteria and viruses. These organisms have co-evolved with their hosts, developing an arsenal of tricks to take advantage of them. In fact, many consider parasites to be a dominant force that drives evolution.

## 25 Space is not a complete vacuum

A vacuum is a space utterly devoid of any molecules, particles or any matter. Yet even the deepest recesses of our universe contain a few hydrogen atoms and photons per cubic metre.

## 26. Hawaii moves 7.5cm closer to Alaska every year

The Earth's crust is split into gigantic pieces called tectonic plates. These plates are in constant motion, propelled by currents in the Earth's upper mantle. Hot, less-dense rock rises before cooling and sinking, giving rise to circular convection currents which act like giant conveyor belts, slowly shifting the tectonic plates above them. Hawaii sits in the middle of the Pacific Plate, which is slowly drifting north-west towards the North American Plate, back to Alaska. The plates' pace is comparable to the speed at which our fingernails grow.



**4. Building a chain**
This process has repeated itself over millions of years, creating the chain of over 20 volcanoes which make up Hawaii.

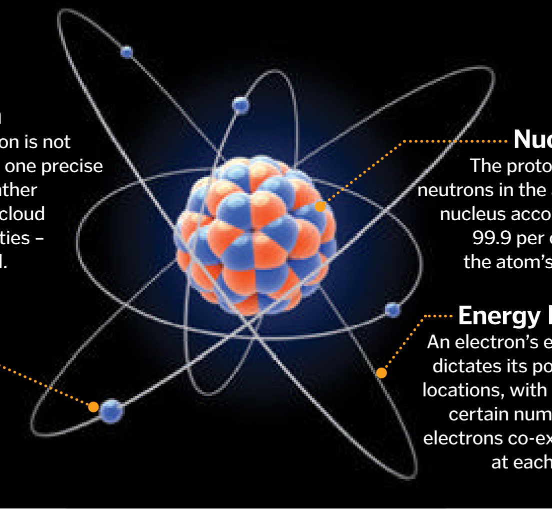
**3. Tectonic movement**
As the Pacific Plate moves north, the volcano drifts off the hot spot and becomes dormant with a new volcano taking its place.

**1. Hot spot**
The Hawaiian archipelago sits on top of a 'hot spot' where a plume of superheated rock rises through the Earth's crust.

**2. Island birth**
Where the hot rock bursts through the ocean floor, it cools and solidifies, forming a volcanic island.

## 27. If you took out all the empty space in our atoms, the human race could fit in the volume of a sugar cube

The atoms that make up the world around us seem solid, but are in fact over 99.99999 per cent empty space. An atom consists of a tiny, dense nucleus surrounded by a cloud of electrons, spread over a proportionately vast area. This is because as well as being particles, electrons act like waves. Electrons can only exist where the crests and troughs of these waves add up correctly. And instead of existing in one point, each electron's location is spread over a range of probabilities – an orbital. They thus occupy a huge amount of space.



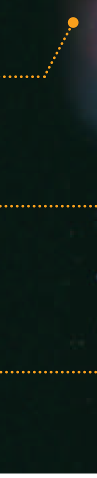
**Electron**
Each electron is not confined to one precise point but rather occupies a cloud of probabilities – ie an orbital.

**Nucleus**
The protons and neutrons in the atom's nucleus account for 99.9 per cent of the atom's mass.

**Energy level**
An electron's energy dictates its possible locations, with only a certain number of electrons co-existing at each level.

## 28. The Sun's fuel won't last for ever

The Sun is fuelled by hydrogen, fusing 620 million tons of hydrogen nuclei into helium each second. This reaction produces solar radiation, which we experience as light and heat, but which also showers us with neutrinos – tiny particles that can pass through matter. In fact, at this very second billions of neutrinos are passing through your body. The Sun is about 4.5 billion years old and, after comparing it to similar stars in our galaxy, astrophysicists reckon it is about halfway through its hydrogen burning stage. That leaves us another 5 billion years before its fuel begins to run low.

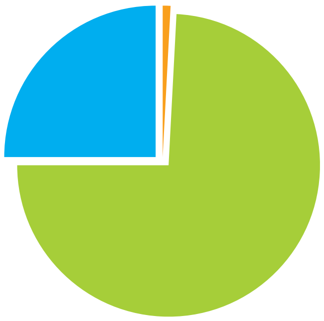


**Stellar cloud**
This dense cloud of gas contracts under gravity, giving birth to a new star.

**Protostar**
If the star is massive enough, its temperature reaches 10 million Kelvin, allowing the star to fuse hydrogen.

**Main-sequence star**
Stars similar to our Sun in size continue to burn hydrogen until their supplies run out.

## 29. Three-quarters of the universe is hydrogen



🟩 **Hydrogen: 74%**
🟦 **Helium: 25%**
🟧 **Heavier elements: 1%**

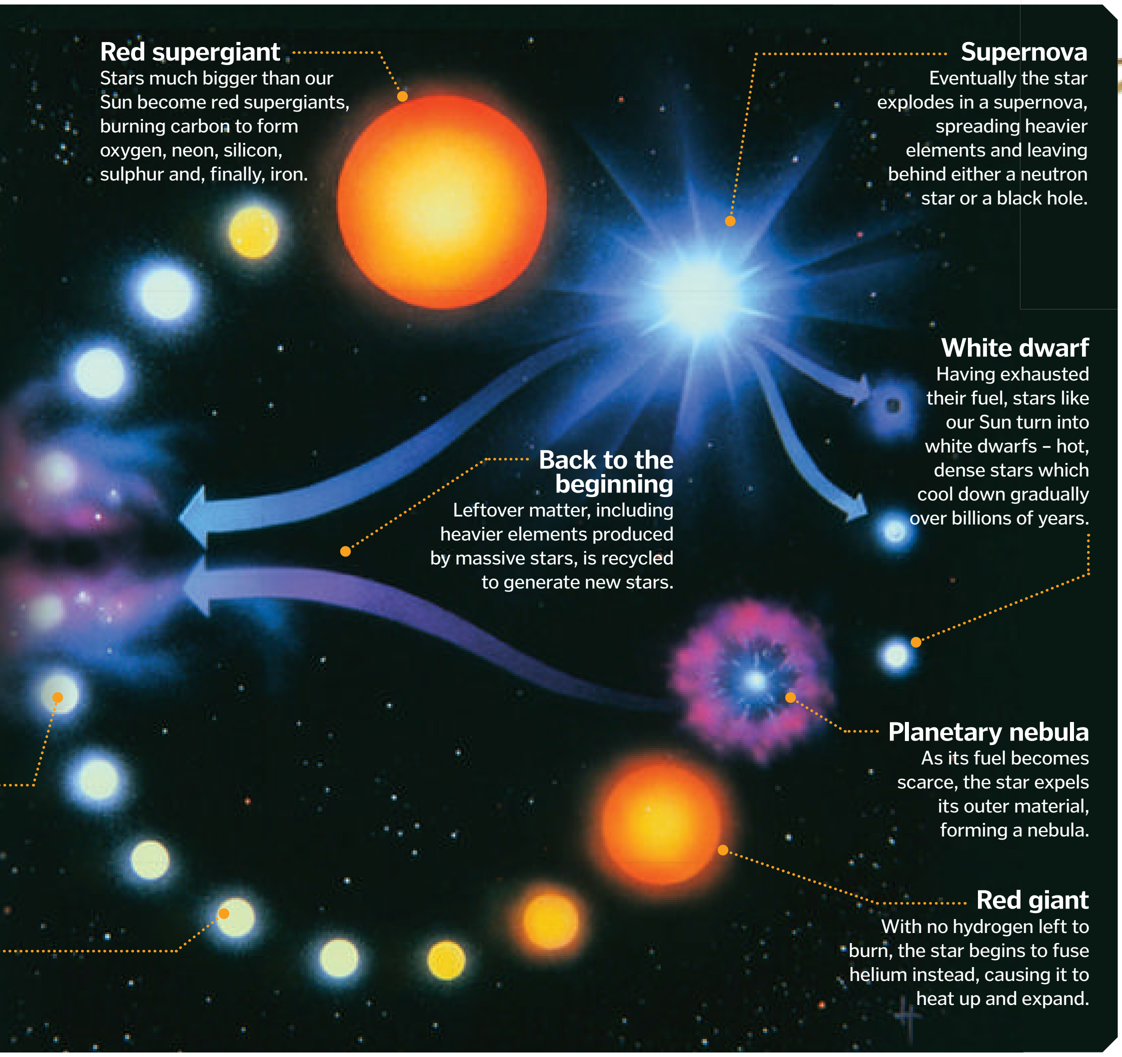
**RECORD BREAKERS**
**MEGA-MAMMAL**

**176,792kg**

## BIGGEST-EVER ANIMAL

A female blue whale is the largest and heaviest animal ever recorded on Earth. It's probably bigger than any land animal that ever walked the planet too, including the dinosaurs.

**DID YOU KNOW?** *Human DNA sequences are around 50 per cent identical to those of a banana!*



**Red supergiant**
Stars much bigger than our Sun become red supergiants, burning carbon to form oxygen, neon, silicon, sulphur and, finally, iron.

**Supernova**
Eventually the star explodes in a supernova, spreading heavier elements and leaving behind either a neutron star or a black hole.

**White dwarf**
Having exhausted their fuel, stars like our Sun turn into white dwarfs – hot, dense stars which cool down gradually over billions of years.

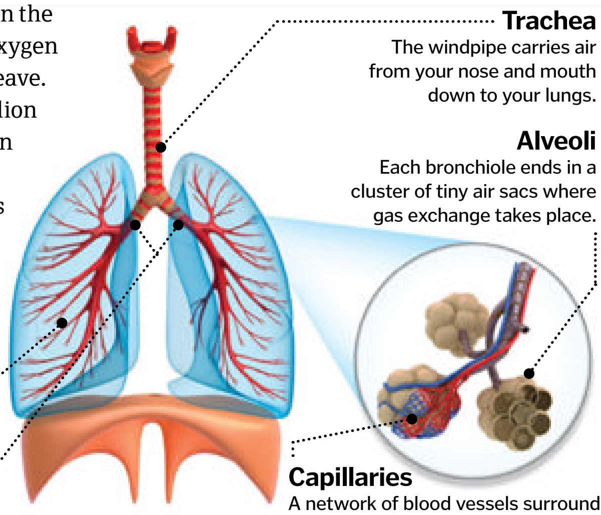
**Back to the beginning**
Leftover matter, including heavier elements produced by massive stars, is recycled to generate new stars.

**Planetary nebula**
As its fuel becomes scarce, the star expels its outer material, forming a nebula.

**Red giant**
With no hydrogen left to burn, the star begins to fuse helium instead, causing it to heat up and expand.

## 30. The surface area of the lungs is equivalent to a tennis court

The lungs facilitate gas exchange between the air we breathe and our blood, allowing oxygen to enter the body and carbon dioxide to leave. This exchange takes place inside 700 million alveoli, tiny hollow air sacs wrapped in an intricate network of blood vessels. The membrane across which the gases pass is about two micrometres (0.00008 inches) thick, 50 times thinner than a sheet of paper and its total surface area adds up to 70 square metres (750 square feet).



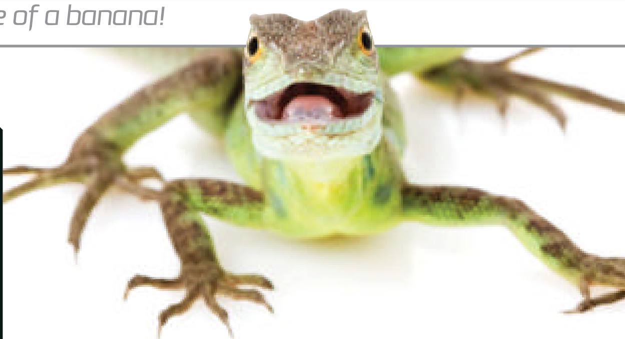
**Trachea**
The windpipe carries air from your nose and mouth down to your lungs.

**Alveoli**
Each bronchiole ends in a cluster of tiny air sacs where gas exchange takes place.

**Bronchioles**
As the bronchi branch out, they form bronchioles, of which there are about 30,000 in each lung.

**Bronchi**
The bronchi connect both left and right lungs to the trachea.

**Capillaries**
A network of blood vessels surrounds the alveoli, transporting oxygen and carbon dioxide in and out of the body.



## 31. Lizards can walk on water

Fringes of skin on the outer edges of the Central/South American basilisk lizard's hind toes increase the feet's surface area, making this impressive trick possible. The lizard slaps its feet down as it runs, creating an upward force and trapping bubbles of air. Its feet also push sideways, helping it to stay upright.

## 32. The universe expands in all directions hourly

Our universe is growing continually, with the space between objects expanding just like an inflated balloon. This fact wasn't discovered until the 1920s, when Edwin Hubble observed that distant galaxies are rushing away from us. Not only that, but the farther a galaxy is from us, the faster it moves away. This groundbreaking observation also implied that the whole universe must once have been contained in a single point, giving rise to the Big Bang theory. According to this model, the cosmos was born 13.7 billion years ago, with all its energy compressed into one incredibly hot and dense point which has been expanding and cooling ever since.

Even more surprisingly, the universe's expansion is accelerating. The reason behind the universe's swelling has been dubbed 'dark energy', but very little is known about this mysterious force which is thought to occupy a staggering 70 per cent of the universe.

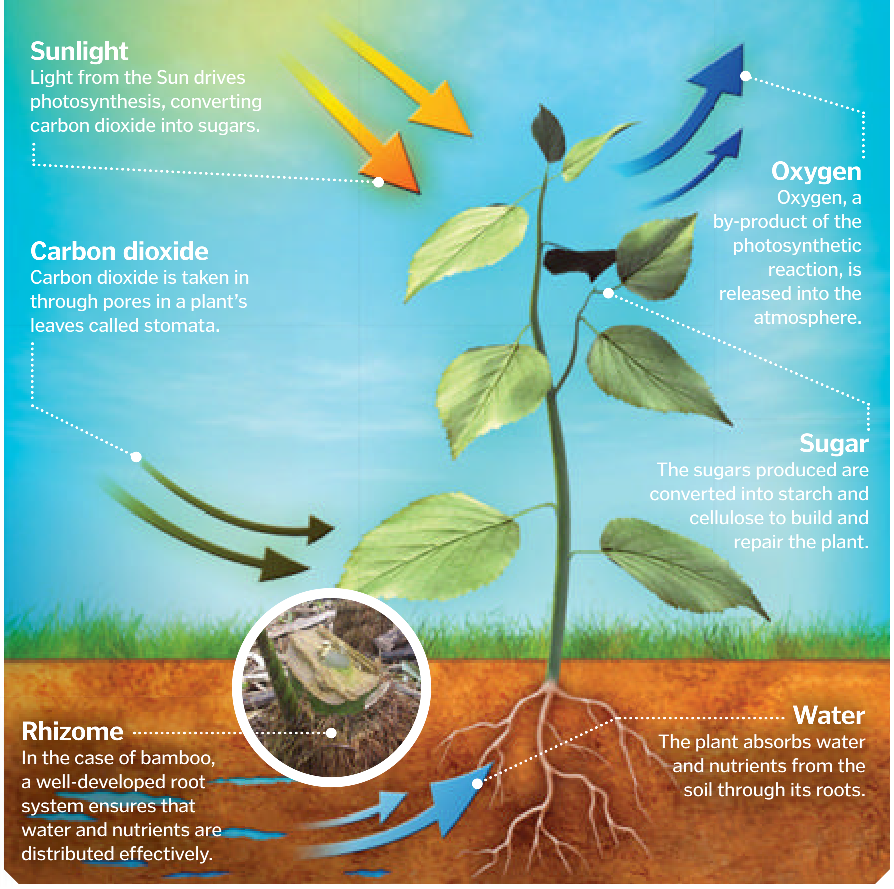
## 33. At light speed it would take 2.5 million years to reach our galactic neighbour

Andromeda is one of our galaxy's closest neighbours, but popping over to borrow some sugar would be quite a trek. By measuring the apparent brightness of its stars, astronomers have estimated that Andromeda is 2.4 x $10^{19}$ kilometres (1.5 x $10^{19}$ miles) away. To avoid drowning in zeros, scientists prefer to measure such distances in light years. As its name suggests, a light year is the distance travelled by light in one year – in other words, a whopping 9.5 trillion kilometres (about six trillion miles) – making Andromeda 2.5 million light years away.

> "It wasn't until 2.4 million years ago that the Homo genus appeared"

## 34. Bamboo is the fastest-growing plant on Earth

While trees grow mostly from the end of their branches, bamboo is actually a grass, so it grows very differently. A bamboo shoot is split into segments which can all host cell division (ie growth), allowing the bamboo to extend a bit like a telescope Equally vital to its record-smashing growth rates (60 centimetres/24 inches per day) is the plant's rhizome, an underground network of roots connecting a cluster of canes. Like all plants, bamboo gets its energy from photosynthesis, but the rhizome enables it to distribute nutrients and water where they are most needed.



**Sunlight**
Light from the Sun drives photosynthesis, converting carbon dioxide into sugars.

**Carbon dioxide**
Carbon dioxide is taken in through pores in a plant's leaves called stomata.

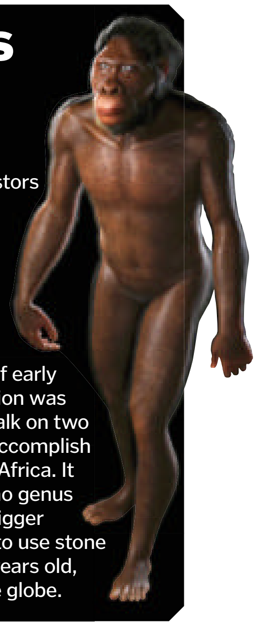
**Rhizome**
In the case of bamboo, a well-developed root system ensures that water and nutrients are distributed effectively.

**Oxygen**
Oxygen, a by-product of the photosynthetic reaction, is released into the atmosphere.

**Sugar**
The sugars produced are converted into starch and cellulose to build and repair the plant.

**Water**
The plant absorbs water and nutrients from the soil through its roots.

## 35. Early humans date back up to 7 million years



It's difficult to define the point when our ancestors became 'human', but one important milestone occurred when the human lineage diverged from that of our closest living relatives: chimpanzees. The last ancestor we shared with chimps lived about 7 million years ago – a relatively short time ago in the 2 billion odd years since life first appeared on Earth. Since then there have been 15-20 different species of early hominid. Another key chapter in human evolution was the beginnings of bipedalism – the ability to walk on two feet. Australopithecus was the first genus to accomplish this feat around 4 million years ago in eastern Africa. It wasn't until 2.4 million years ago that the Homo genus appeared. Their distinguishing feature was a bigger brain and they we [redacted] ncestors to use stone tools. Homo sapie [redacted] 00,000 years old, emerging in Afric [redacted] cross the globe.

## 36. Gravity is only 3% weaker 100km above the Earth

According to the laws of gravity, any two objects with mass attract each other. For this effect to be noticeable, one of the objects needs to have a considerable mass; at roughly 6 x $10^{24}$ kilograms (1.3 x $10^{25}$ pounds), our planet fits the bill nicely. Gravity decreases the farther you are from Earth's centre, but given that standing on its surface you are already 6,370 kilometres (3,960 miles) away from the core, a 100-kilometre (62-mile) increase makes a relatively small difference. Air pressure, on the other hand, is caused by the sheer weight of the air molecules above you. Standing at sea level, the air above you causes a pressure equivalent to about 1,000 kilograms (2,205 pounds). Luckily this pressure pushes on us in all directions. Water weighs about 800 times more than air, so exerts a far greater pressure; in fact, at just ten metres (33 feet) underwater, the pressure would be double.

## 37 Polar bears are nearly undetectable by infrared cameras

Thermal cameras detect the heat lost by a subject as infrared, but polar bears are experts at conserving heat. The bears keep warm due to a thick layer of blubber under the skin. Add to this a dense fur coat and they can endure the chilliest Arctic day.

## 38 Stomach acid is strong enough to dissolve razor blades

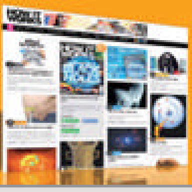
Your stomach digests food thanks to highly corrosive hydrochloric acid with a pH of 2 to 3. This acid also attacks your stomach lining, which protects itself by secreting an alkali bicarbonate solution. The lining still needs to be replaced continually, and it entirely renews itself every four days.

## 39 Alpha radiation can be deadly but a sheet of paper can stop it

As an unstable radioactive atom decays, it ejects particles and energy, producing alpha, beta and gamma radiation. Alpha particles carry the strongest charge so can cause the most harm. Their large mass, however, stops them penetrating very far into matter, so they're only likely to cause damage if ingested.

## 40 The Earth is a giant magnet

Earth's inner core is a sphere of solid iron, surrounded by liquid iron. Variations in temperature and density create currents in this iron, which in turn produce electrical currents. Lined up by the Earth's spin, these currents combine to create a magnetic field, used by compass needles worldwide.



**AMAZING VIDEO!** SCAN THE QR CODE FOR A QUICK LINK

**Watch the mega-tides at the Bay of Fundy**

www.howitworksdaily.com

**DID YOU KNOW?** *The cornea in the eye is the only tissue in the body that doesn't require blood*

# 41. Nerve impulses can travel as fast as 200mph

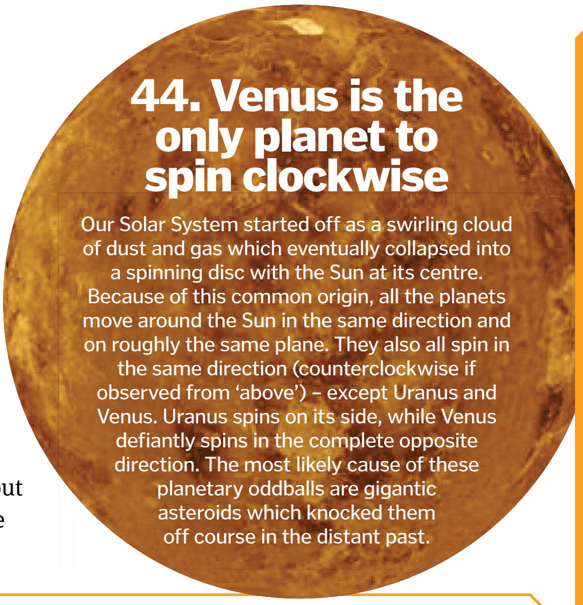
Electrical signals are the body's principal means of communication, controlling everything from your heartbeat to pain. The nervous system is a network of millions of neurons – tiny messenger cells which transmit information using electrical signals called nerve impulses. By controlling the flow of ions, each neuron can build up an electrical charge and transmit it down its axon, a long branch which passes the impulse on to the next neuron. The speed of nervous impulses varies but the fastest signals are carried within motor neurons. These relay messages from the brain telling muscles to contract.

# 42. The difference between tides can be as great as 17m

The extreme tides in eastern Canada's Bay of Fundy are caused by tidal resonance. All over the globe, high tides occur every 12 and a half hours. The Bay of Fundy is peculiar in that it takes 13 hours for seawater to slosh into the mouth of the bay, to its head and then back out to sea, roughly matching the rhythm of the tides. As each tide rises, it therefore amplifies the water's sloshing motion – just like someone giving a child on a swing a small push at just the right moment. These two bulges result in two high tides, which sweep around the globe at intervals of 12 and a half hours.

# 43. Energy is neither created nor destroyed

Known as the law of conservation of energy, this principle is key to understanding our entire universe. Energy can't be created or destroyed, but it can change form. Think about a moving car, for example. Chemical energy contained in the fuel is converted into mechanical energy by the motor. This propels the car forward, transforming into kinetic energy. Step on the brake and this energy is converted into heat and sound. Energy sometimes seems to disappear, but this usually means it is being stored as potential energy, like a stretched spring. Although energy is never destroyed, it can be 'lost' when converted into unwanted forms, eg a traditional light bulb expends lots of energy as heat rather than light.



# 44. Venus is the only planet to spin clockwise

Our Solar System started off as a swirling cloud of dust and gas which eventually collapsed into a spinning disc with the Sun at its centre. Because of this common origin, all the planets move around the Sun in the same direction and on roughly the same plane. They also all spin in the same direction (counterclockwise if observed from 'above') – except Uranus and Venus. Uranus spins on its side, while Venus defiantly spins in the complete opposite direction. The most likely cause of these planetary oddballs are gigantic asteroids which knocked them off course in the distant past.

# 45. Sound moves faster in water than air

Sound is a vibration. It travels as a compression (or longitudinal) wave when particles (molecules or atoms) collide with one another, passing on the vibration. Sound therefore can't cross a vacuum but needs a medium to pass through, and its speed is determined by the properties of that medium. In general, sound travels fastest in a solid, then a liquid and slowest in a gas. Inside a solid, particles are packed tightly together, meaning vibrations are passed on easily. In a liquid particles are more spaced out, making it harder for vibrations to be transmitted from one particle to the next, but they can travel faster than when passing through a gaseous medium like air.

### Air

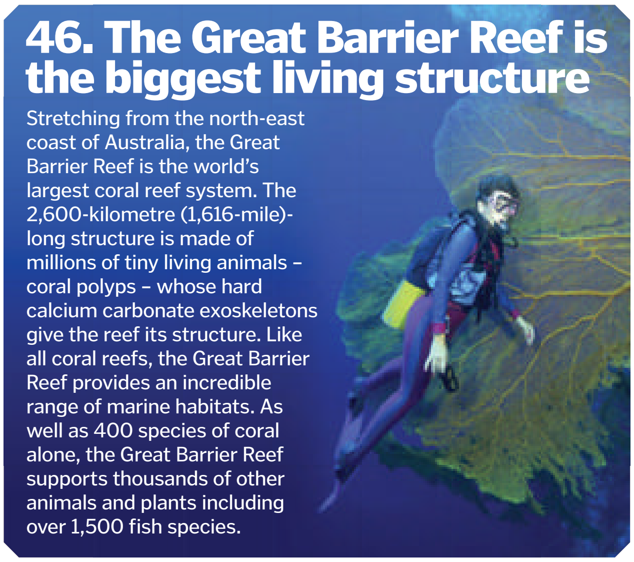
At room temperature, sound travels through air at 344m (1,129ft)/sec. Lower the thermostat and the drop in air density slows it down significantly.

### Water

Sound travels at 1,500m (4,921ft)/sec through water, as it's a much denser medium than air.

### Steel

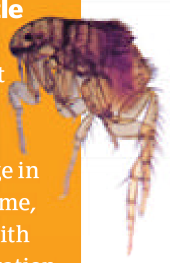
The rigid structure of steel allows sound waves to travel at a swift 6,000m (19,685ft)/sec – 17 times faster than through air.



# 46. The Great Barrier Reef is the biggest living structure

Stretching from the north-east coast of Australia, the Great Barrier Reef is the world's largest coral reef system. The 2,600-kilometre (1,616-mile)-long structure is made of millions of tiny living animals – coral polyps – whose hard calcium carbonate exoskeletons give the reef its structure. Like all coral reefs, the Great Barrier Reef provides an incredible range of marine habitats. As well as 400 species of coral alone, the Great Barrier Reef supports thousands of other animals and plants including over 1,500 fish species.

# 47 A flea can accelerate faster than the Space Shuttle



A jumping flea reaches dizzying heights of about eight centimetres (three inches) in a millisecond. Acceleration is the change in speed of an object over time, often measured in 'g's, with one g equal to the acceleration caused by gravity on Earth (9.8 metres/32.2 feet per square second). Fleas experience 100 g, while the Space Shuttle peaked at around 5 g. The flea's secret is a stretchy rubber-like protein which allows it to store and release energy like a spring.

# 48 If you could drive up, you'd arrive in space in about an hour

The Kármán Line at 100 kilometres (62 miles) in altitude is generally accepted as the boundary of space. Driving at a leisurely 90 kilometres (56 miles) per hour, a trip to space would therefore take just 67 minutes.

# 49 Stretched out, the DNA from one human cell would be 2m

The DNA in each cell contains all the instructions necessary to build a person, coiled up tightly inside chromosomes in the nucleus. There are roughly 3 billion chemical letters (bases) in your DNA.

# 50 The gas cloud Sagittarius B2 contains a billion, billion, billion litres of alcohol

The alcohol in question is vinyl alcohol as opposed to ethanol. Although scientists don't yet know how it got there, it's thought these molecules could provide clues as to how complex organic compounds form in space.

© Thinkstock; SPL; NASA; Corbis; Alamy

> "As noble gases show extremely low reactivity only a few hundred noble gas compounds have been formed"

# How do noble gases work?

## What makes this select bunch of chemical elements so 'noble'?

There are six naturally occurring noble gases found around our world and beyond. These are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). Together they form Group 18 of the periodic table and are characterised by their lack of colour, smell, taste and flammability in their natural state.

Despite being historically referred to as rare and inert, noble gases – which were designated 'noble' due to their apparent reluctance to undergo a chemical reaction – are nothing of the sort. In fact, all of these gases are found in Earth's atmosphere and each is capable of being chemically active and producing compounds.

The majority of the noble gases – ie argon, krypton, neon and xenon – are formed via liquefaction and fractional distillation techniques, however helium is attained by separating it from natural gas and radon by isolating it from the radioactive decay of radium compounds.

As noble gases show extremely low chemical reactivity, while they are not inert, only a few hundred noble gas compounds have been formed to date, with xenon varieties making up the bulk. In theory, though, radon is more reactive than xenon, so should form chemical bonds more readily. However, its high radioactivity and short half-life are the key factors which prevent this.

There are many applications for noble gases (see the boxout below for some notable examples). The most obvious and visible of these are illuminated signs, light bulbs and lamps, with xenon, argon and neon commonly used due to their lack of chemical reactivity. Using these gases helps to preserve filaments in light bulbs and grants distinctive colours when used in gas-discharge lamps – as demonstrated by the main image on this page. ✿

## Where are noble gases used?

### Arc lamps

A specialised type of gas-discharge lamp, arc lights pass electricity through a bulb full of ionised gas, such as xenon or argon. They're used in IMAX cinemas among other places.

### Blimps

Today, most blimps are filled with helium due to its lightness and incombustibility. Hydrogen was used originally but was phased out due to its high flammability.

### MRI scanners

One of the most advanced pieces of medical equipment, magnetic resonance imaging scanners use liquid helium to cool the superconducting magnets inside.

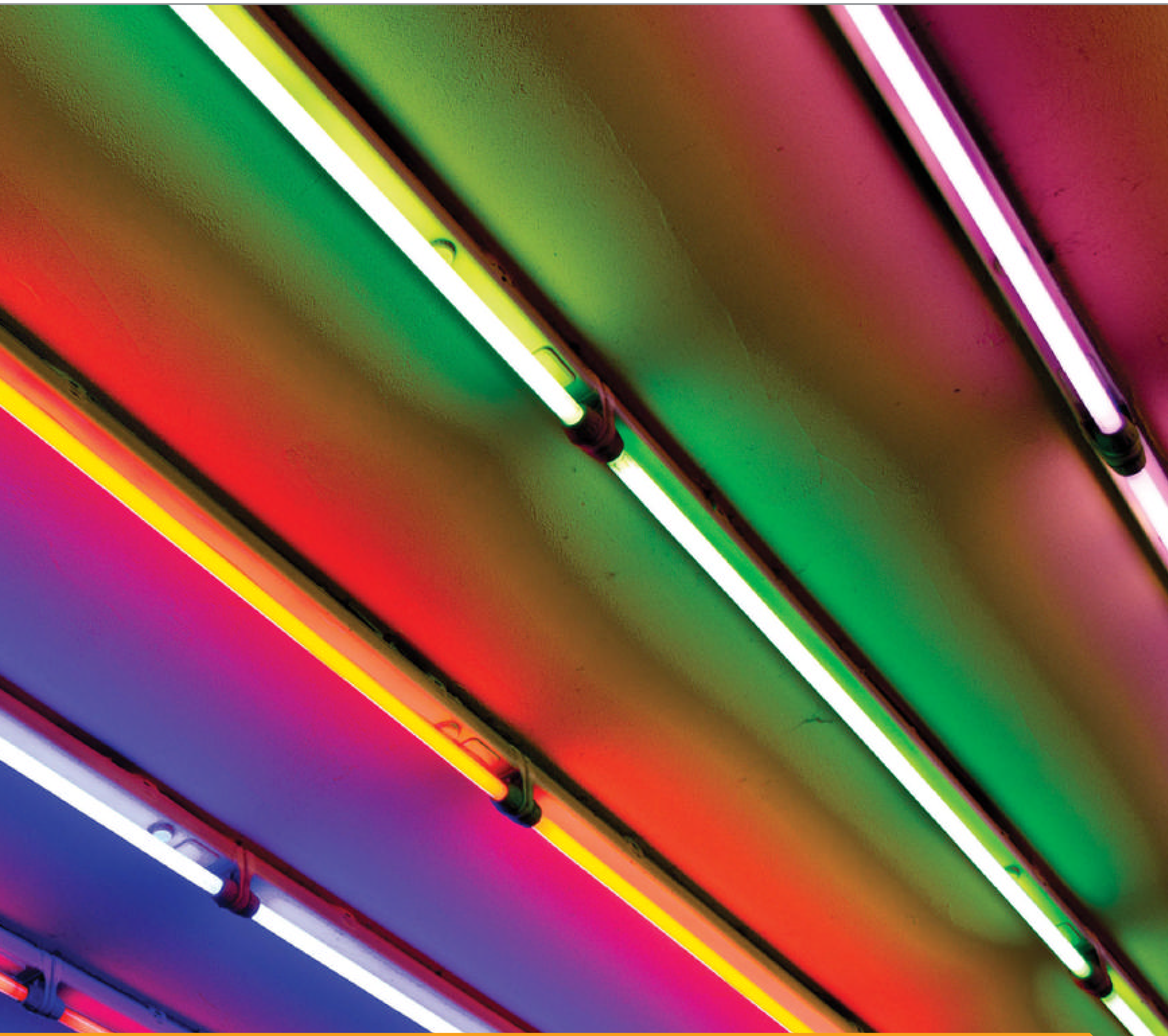
**RECORD BREAKERS**
**BOILING COLD**

# -268.9°C

## LOWEST BOILING POINT

-268.9 degrees Celsius (-452 degrees Fahrenheit) is the chilly boiling point of the noble gas helium. It is the lowest of any element in the entire periodic table.

**DID YOU KNOW?** *The first noble gas compound was formed from xenon in 1962 by British chemist Neil Bartlett*



### Illuminated signs

Many illuminated signs and billboards utilise noble gases due to their ability to generate vibrant colours when ionised – neon lights being a prime example.

### Refrigerants

Due to their incredibly low boiling points – for instance, argon boils at -186 degrees Celsius (-302.8 degrees Fahrenheit) – the Group 18 gases are often used in cryogenics.

### Radiotherapy

Despite the noble gas radon being highly radioactive and able to cause cancer, it can also be used as part of radiotherapy treatments to control or kill malignant cells.

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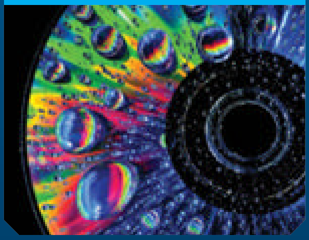

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## HEAD 2 HEAD

USING UV

**1. NOT DEADLY**

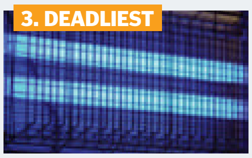
**Dental tools**

Allowing for clarity not possible in our visible light spectrum, analysing teeth with UV grants dentists a clearer view to look for defects and blemishes.

**2. DEADLY**

**Sunbed**

Sunbeds bombard the skin with UV rays via a series of specialised bulbs to top up tans, but it's widely known they pose a risk to users' health.


**3. DEADLIEST**

**Bug zapper**

With most insects attracted to UV light at wavelengths around 360 nanometres, ultraviolet lamps are ideal for luring bugs in to be zapped.

**DID YOU KNOW?** *The UV spectrum is divided into ten subtypes based on wavelength and photon energy*

# Breaking down gas chromatography

Need to split a substance into its base components? Then you need to get hold of a gas chromatograph…

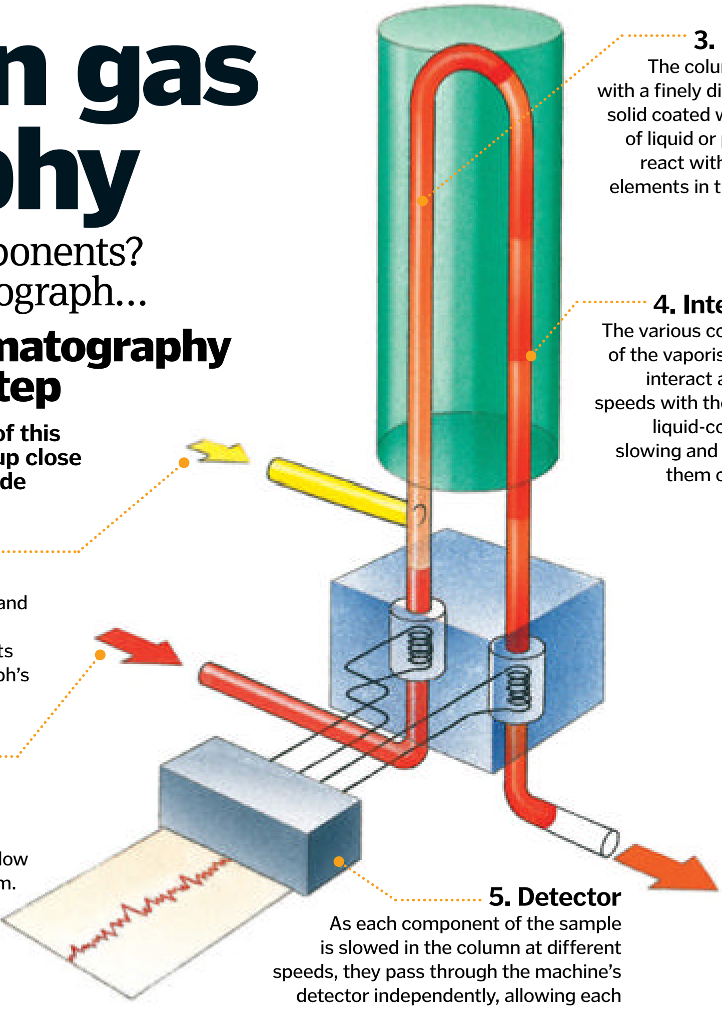
Chromatography is the process of separating a mixture into its core components for analysis or reuse. Gas chromatography uses an inert gas as a carrying mechanism within that separation, with samples introduced to the gas and then filtered through a solid distillation column.

Key to the process is the retardation (slowing) of the mixture's elements in the column, which is achieved by filling the latter with a finely divided inert solid coated with a thin layer of reactive liquid or polymer. The stream of gas passes the coated solid and, while the inert gas – by its very nature – won't react with it, the additional elements it is carrying will.

Each component doesn't react with the solid simultaneously, however. This means the sample breaks down over time, with each element leaving the column at a certain point depending on its composition. As such, a mixture of various substances can be split into its constituent parts, allowing each to be quantified, studied and/or filtered.

## Gas chromatography step-by-step

**Follow the stages of this chemical process up close with our handy guide**



**1. Inert**
A stream of inert gas – eg helium or argon – is pumped through the machine in a constant flow as a carrying mechanism.

**2. Sample**
The sample – blood, for instance – is vaporised and introduced to the gas stream, which transports it into the chromatograph's separating column.

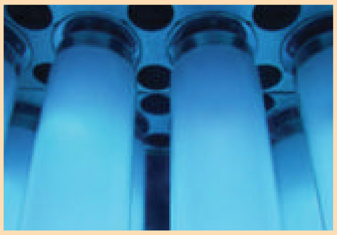
**3. Column**
The column is filled with a finely divided inert solid coated with a layer of liquid or polymer to react with individual elements in the sample.

**4. Interaction**
The various components of the vaporised sample interact at different speeds with the polymer/liquid-coated solid, slowing and separating them one by one.

**5. Detector**
As each component of the sample is slowed in the column at different speeds, they pass through the machine's detector independently, allowing each substance to be measured and filtered.

# Understanding ultraviolet

Discover what this form of electromagnetic radiation is all about



Ultraviolet (UV) radiation is a part of the electromagnetic spectrum that extends from the end of visible light through to X-rays. This part of the spectrum is undetectable to the naked eye, with only a few insects capable of seeing it, but it's indirectly visible to us via fluorescent objects, which emit the radiation at a lower energy level.

The spectrum of ultraviolet light lies between the wavelengths of 400 nanometres (near-visible light) through to just ten nanometres (near-X-ray). This spectrum is divided into four major categories: near (400-300 nanometres), middle (300-200 nanometres), far (200-100 nanometres) and extreme (100-10 nanometres). It's also split into ten subtypes, which possess different qualities for various applications.

UV radiation is produced by high-temperature surfaces, such as stars, and is emitted in a continuous spectrum. On our planet, for example, the majority of UV light is found in light rays emanating from the Sun, where it constitutes about ten per cent when in the near-vacuum of space. However, the vast majority of this UV radiation is absorbed by ozone in the Earth's atmosphere, with only limited quantities of the ultraviolet A (UVA) subtype reaching the surface.

UV rays from the Sun are to blame for sunburn

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**-272°C**

**COLDEST PLACE IN SPACE**

The Boomerang Nebula 5,000 light years away has a temperature of just over one degree Kelvin, caused by its rapid expansion. It's the only known object colder than cosmic background radiation.

**DID YOU KNOW?** *Lord Kelvin, AKA William Thomson, established the first physics laboratory in Britain in Glasgow*

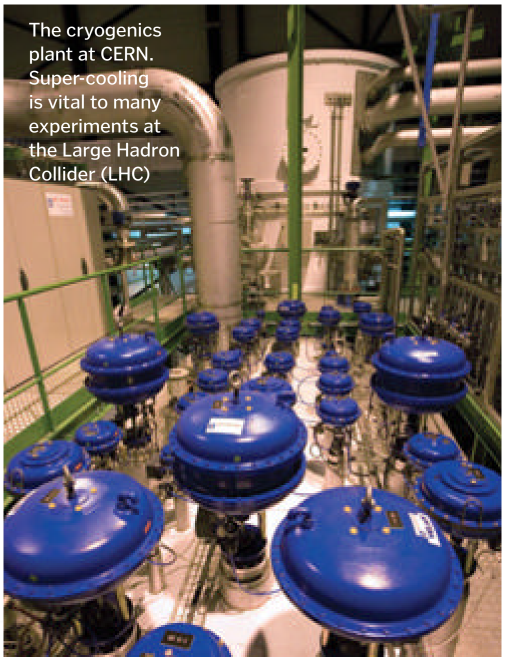
# What is absolute zero?

Learn the benefits of this extreme temperature and why we're bent on finding out how low we can go…

The lowest temperature – at least theoretically – is -273.15 degrees Celsius (-459.67 degrees Fahrenheit), or 0 degrees Kelvin. The latter is the SI unit of temperature named after Lord Kelvin, who devised his scale based on the laws of thermodynamics in 1848. At this point no more heat can be removed from a system as it has reached a stage of absolute cold.

The more heat an object has, the more its atoms move around and vice versa. As the temperature approaches absolute zero, atoms move very slowly and, in theory, at 0 degrees Kelvin there should be no movement, although according to experimental evidence there is some minimal vibrational motion.

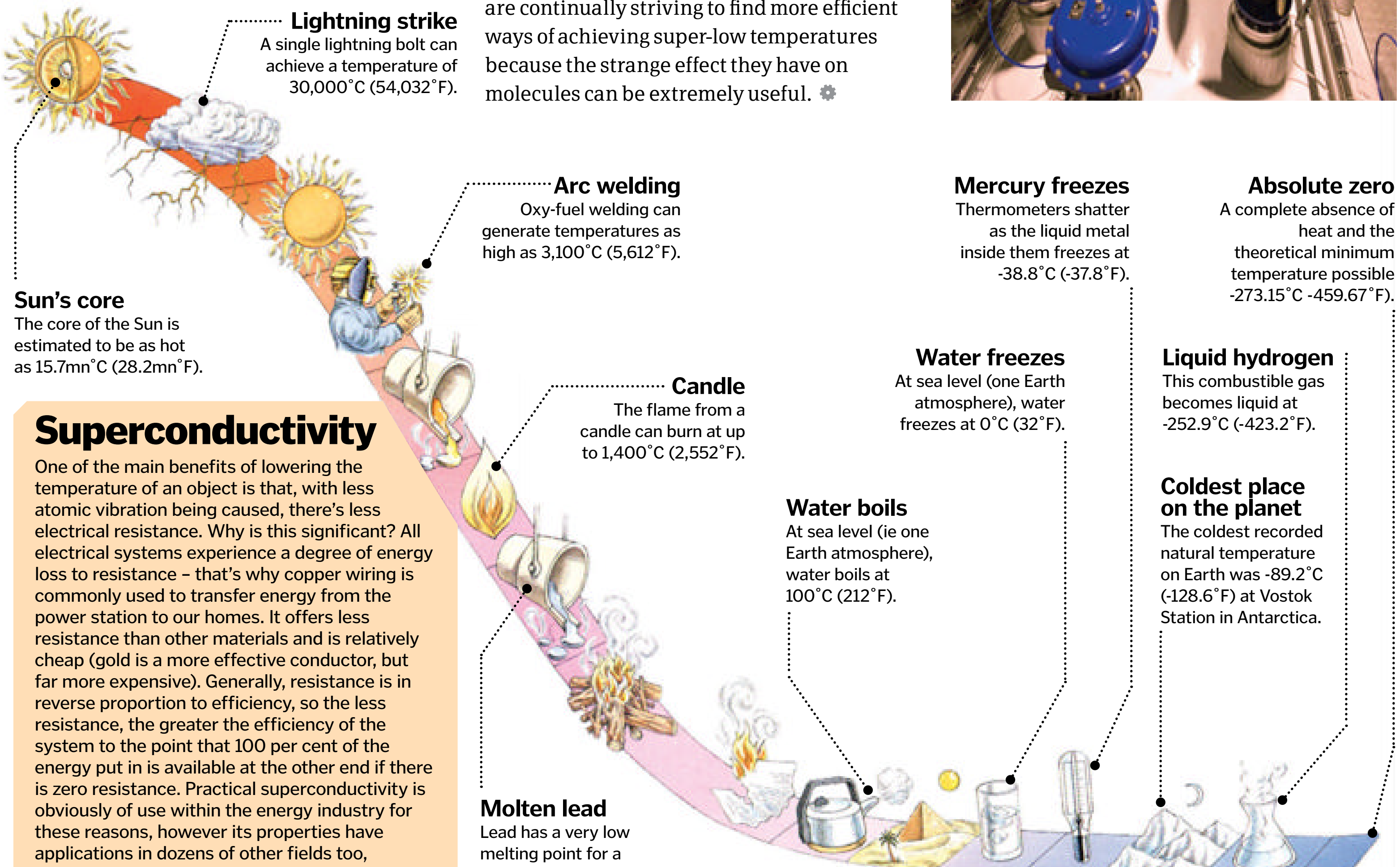
The lowest temperature achieved by man was in a Massachusetts Institute of Technology (MIT) lab in 2003, where a cloud of sodium atoms was cooled to 0.45 nanokelvin, or less than half one-billionth of a degree Kelvin above absolute zero. The reason why it's so difficult to achieve this temperature is because it requires an exponential amount of energy to continually lower the temperature to extreme cold – to the point that it needs an infinite amount of energy to reach absolute zero. Nevertheless, scientists are continually striving to find more efficient ways of achieving super-low temperatures because the strange effect they have on molecules can be extremely useful.



The cryogenics plant at CERN. Super-cooling is vital to many experiments at the Large Hadron Collider (LHC)

## The temperature scale

**How It Works looks at one of the hottest temperatures through to one of the coldest**



**Sun's core**
The core of the Sun is estimated to be as hot as 15.7mn°C (28.2mn°F).

**Lightning strike**
A single lightning bolt can achieve a temperature of 30,000°C (54,032°F).

**Arc welding**
Oxy-fuel welding can generate temperatures as high as 3,100°C (5,612°F).

**Candle**
The flame from a candle can burn at up to 1,400°C (2,552°F).

**Molten lead**
Lead has a very low melting point for a metal – just 327.5°C (621.5°F).

**Water boils**
At sea level (ie one Earth atmosphere), water boils at 100°C (212°F).

**Water freezes**
At sea level (one Earth atmosphere), water freezes at 0°C (32°F).

**Mercury freezes**
Thermometers shatter as the liquid metal inside them freezes at -38.8°C (-37.8°F).

**Coldest place on the planet**
The coldest recorded natural temperature on Earth was -89.2°C (-128.6°F) at Vostok Station in Antarctica.

**Liquid hydrogen**
This combustible gas becomes liquid at -252.9°C (-423.2°F).

**Absolute zero**
A complete absence of heat and the theoretical minimum temperature possible -273.15°C -459.67°F).

## Superconductivity

One of the main benefits of lowering the temperature of an object is that, with less atomic vibration being caused, there's less electrical resistance. Why is this significant? All electrical systems experience a degree of energy loss to resistance – that's why copper wiring is commonly used to transfer energy from the power station to our homes. It offers less resistance than other materials and is relatively cheap (gold is a more effective conductor, but far more expensive). Generally, resistance is in reverse proportion to efficiency, so the less resistance, the greater the efficiency of the system to the point that 100 per cent of the energy put in is available at the other end if there is zero resistance. Practical superconductivity is obviously of use within the energy industry for these reasons, however its properties have applications in dozens of other fields too, including medicine, transport and astronomy.

© DK Images; SPL

> *"The cells are all in contact with capillaries, so hormones can be fed directly into the bloodstream"*

# How the pancreas works

Learn how the workhorse of the digestive system helps to break down food and control our blood sugar levels

The pancreas is a pivotal organ within the digestive system. It sits inside the abdomen, behind the stomach and the large bowel, adjacent to the spleen. In humans, it has a head, neck, body and tail. It is connected to the first section of the small intestine, the duodenum, by the pancreatic duct, and to the bloodstream via a rich network of vessels. The function of the pancreas is best considered by thinking about the two types of cell it contains: endocrine and exocrine.

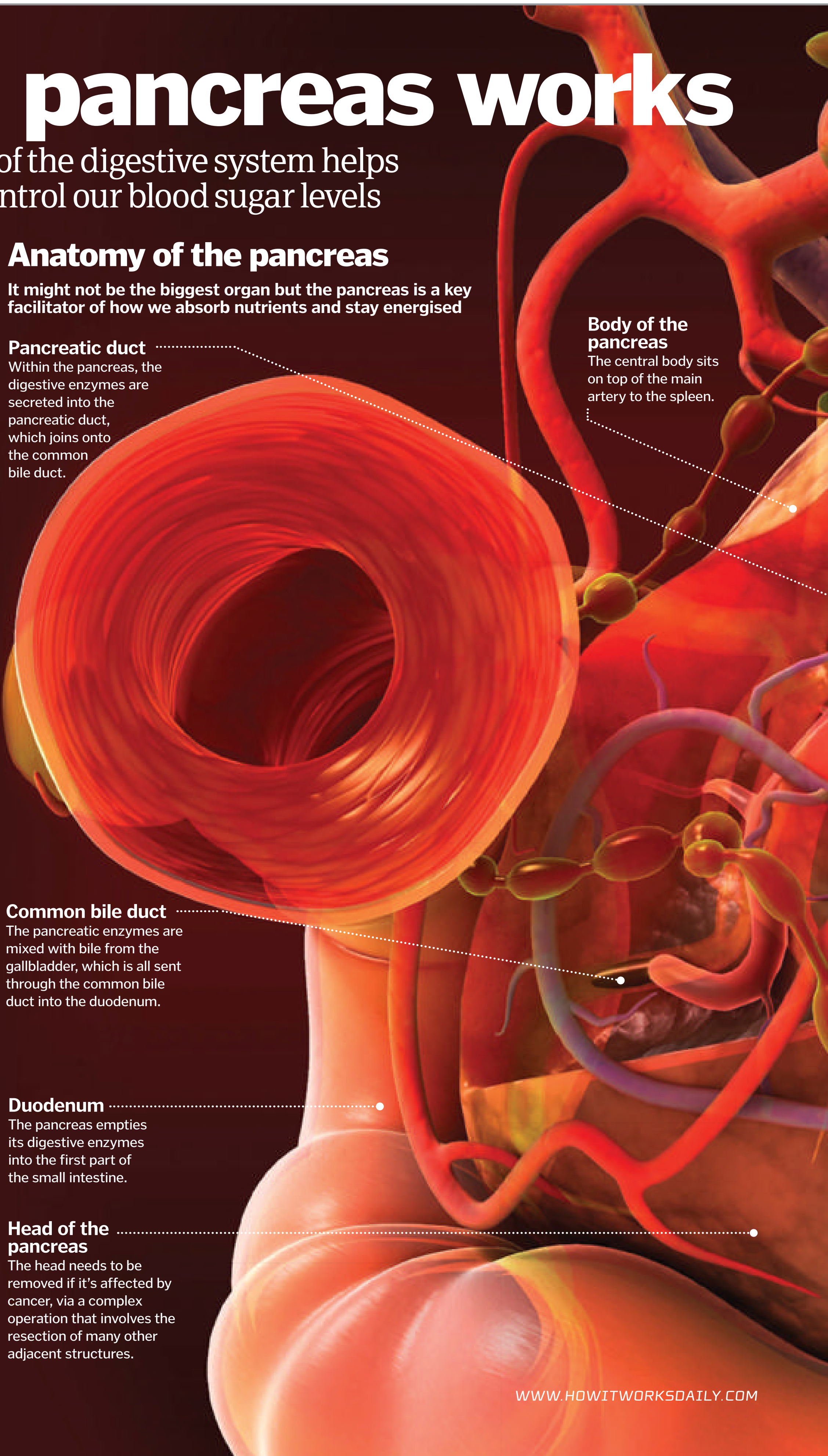
The endocrine pancreas is made up of clusters of cells called islets of Langerhans, which in total contain approximately 1 million cells and are responsible for producing hormones. These cells include alpha cells, which secrete glucagon, and beta cells which generate insulin. These two hormones have opposite effects on blood sugar levels throughout the body: glucagon increases glucose levels, while insulin decreases them.

The cells here are all in contact with capillaries, so hormones which are produced can be fed directly into the bloodstream. Insulin secretion is under the control of a negative-feedback loop; high blood sugar leads to insulin secretion, which then lowers blood sugar with subsequent suppression of insulin. Disorders of these cells (and thus alterations of hormone levels) can lead to many conditions, including diabetes. The islets of Langerhans are also responsible for producing other hormones, like somatostatin, which governs nutrient absorption among other things.

The exocrine pancreas, meanwhile, is responsible for secreting digestive enzymes. Cells are arranged in clusters called acini, which flow into the central pancreatic duct. This leads into the duodenum – part of the small bowel – to come into contact with and aid in the digestion of food. The enzymes secreted include proteases (to digest protein), lipases (for fat) and amylase (for sugar/starch). Secretion of these enzymes is controlled by a series of hormones (gastrin, cholecystokinin and secretin), which are released from the stomach and duodenum in response to the stretch from the presence of food. ✿

## Anatomy of the pancreas

**It might not be the biggest organ but the pancreas is a key facilitator of how we absorb nutrients and stay energised**



**Pancreatic duct**
Within the pancreas, the digestive enzymes are secreted into the pancreatic duct, which joins onto the common bile duct.

**Body of the pancreas**
The central body sits on top of the main artery to the spleen.

**Common bile duct**
The pancreatic enzymes are mixed with bile from the gallbladder, which is all sent through the common bile duct into the duodenum.

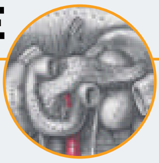
**Duodenum**
The pancreas empties its digestive enzymes into the first part of the small intestine.

**Head of the pancreas**
The head needs to be removed if it's affected by cancer, via a complex operation that involves the resection of many other adjacent structures.

## KEY DATES
PANCREATIC PAST

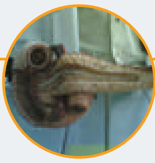
**336 BCE**
The Greek anatomist who will first discover the pancreas – Herophilus – is born.

**1st century CE**
The name 'pancreas' is given, meaning 'all flesh', as it's believed to serve solely as a cushioning, protective fat pad.



**1642**
The pancreatic duct is found in Padua, Italy. It is named after its discoverer: the duct of Wirsung.

**1889**
German scientists remove the pancreas in a dog and induce diabetes, proving an irrefutable link.



**1966**
The first modern human pancreatic transplant is performed in the USA on a 28-year-old female patient.

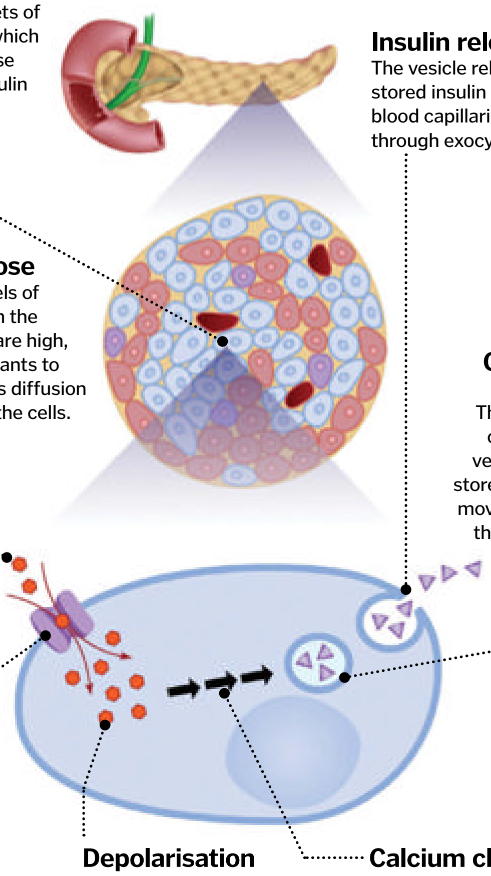
**DID YOU KNOW?** *In the UK, 80 per cent of acute pancreatitis cases are caused by gallstones or excessive alcohol ingestion*

**Tail of the pancreas**
This is the end portion of the organ and is positioned close to the spleen.

**Blood supply**
The pancreas derives its blood supply from a variety of sources, including vessels running to the stomach and spleen.

## What brings on diabetes?

Diabetes is a condition where a person has higher blood sugar than normal. It is either caused by a failure of the pancreas to produce insulin (ie type 1, or insulin-dependent diabetes mellitus), or resistance of the body's cells to insulin present in the circulation (ie type 2, or non-insulin-dependent diabetes mellitus). There are also other disorders of the pancreas. Inflammation of the organ (ie acute pancreatitis) causes severe pain in the upper abdomen, forcing most people to attend the emergency department as it can be life threatening. In contrast, cancer of the pancreas causes gradually worsening pain which can often be mistaken for other ailments.



**Beta cells**
It is the beta cells within the islets of Langerhans which control glucose levels and insulin secretion.

**Insulin released**
The vesicle releases its stored insulin into the blood capillaries through exocytosis.

**High glucose**
When the levels of glucose within the bloodstream are high, the glucose wants to move down its diffusion gradient into the cells.

**Calcium effects**
The calcium causes the vesicles that store insulin to move towards the cell wall.

**GLUT2**
This is a glucose-transporting channel, which facilitates the uptake of glucose into the cells.

**Depolarisation**
The metabolism of glucose leads to changes in the polarity of the cell wall and an increase in the number of potassium ions.

**Calcium channels**
Changes in potassium levels cause voltage-gated calcium channels to open in the cell wall, and calcium ions to flow into the cell.

© Corbis; Süleyman Habib

## Does the pancreas vary in humans and animals?

Every vertebrate animal has a pancreas of some form, meaning they are all susceptible to diabetes too. The arrangement, however, varies from creature to creature. In humans, the pancreas is most often a single structure that sits at the back of the abdomen. In other animals, the arrangement varies from two or three masses of tissue scattered around the abdomen, to tissue interspersed within the connective tissue between the bowels, to small collections of tissue within the bowel mucosal wall itself. One of the other key differences is the number of ducts that connect the pancreas to the bowel. In most humans there's only one duct, but occasionally there may be two or three – and sometimes even more. In other animals, the number is much more variable. However, the function is largely similar, where the pancreas secretes digestive enzymes and hormones to control blood sugar levels.

# CCTV

Discover how London keeps traffic flowing using cameras, computers and lots of skilled technicians

**RECORD BREAKERS**
**JUMBO JAM**

# 99.7km

## LONGEST-EVER TAILBACK

The not-so-proud city which lays claim to this staggering record is Beijing, China, which saw this monster traffic jam form in August 2010. Incredibly, it took some drivers up to 12 days to escape!

**DID YOU KNOW?** *TfL has a Twitter feed (@TfLOfficial) which it uses to inform Londoners of congestion and traffic conditions*

New technology is tested and camera repairs are performed in a secure lab at the heart of the London Traffic Control Centre

The London Streets Traffic Control Centre (LSTCC) in south London is the hub for one of the most sophisticated CCTV systems on the planet. It needs to be, because it's responsible for most of Greater London's transport infrastructure and covers hundreds of square kilometres within the M25 circular motorway, streamlining the day-to-day lifeblood of one of the most traffic-intensive cities on Earth. More than 6,000 lights and 3,250 cameras monitor the streets and control traffic across 14,000 kilometres (8,700 miles) of urban highways and busy city roads. They're there to help manage flow at peak times, divert vehicles around congestion hotspots and keep London's drivers, cyclists and pedestrians informed using an impressive arsenal of technologies and a highly skilled workforce.

"The LSTCC is there to keep London moving," chief engineer Brendan Sleight tells us as we cross a curious revolving security door that leads into the more sensitive areas of the building. "It's a bit like air traffic control at Heathrow Airport or the railways: we cover the whole of the road traffic network across all of London – it's our responsibility."

We enter the 'brain' of the LSTCC, the control centre, and it's certainly not disappointing. Row upon row of monitors – three or four for each of the dozens of operators – display images from every corner of the capital. In the middle of the centre are a handful of core operators – the people who receive alerts and distribute them to the relevant staff in specialised departments. Behind them is a bank of giant screens that dominates the room, showing a map of London and myriad icons.

We speak to an operator who's picked up an alert from the police. The computer tells her it's not a major incident, but she won't know its exact nature until she looks at the camera that monitors that stretch of road. Admittedly to our slight disappointment, it's just a broken-down car, but she's able to gauge it's not going to obstruct traffic on the busy highway as it's on the hard shoulder. So with the police already on the scene, the operator simply notifies drivers via the TfL Twitter feed and website.

"The skill and knowledge of an operator is irreplaceable," Sleight says. "You've got these people who know what 'normal' looks like – they can just look at something and instantly see that it's normal. It's really difficult, for example, to program for a situation where a bus has pulled over and another bus is behind it, waiting for the bus in front to decant the passengers onto it. It's not difficult, on the other hand, to program the system to tell an operator to come and have a look at it." Es George, who heads up operations at LSTCC, reiterated the importance of skilled operators who instinctively know what's 'normal'.

Bumper-to-bumper traffic moving at 50 kilometres (30 miles) per hour at rush hour on some stretches of the busy North Circular Road might be standard. But at 2pm, or at rush hour on a different road, it might be considered unusually congested and require attention. ▶

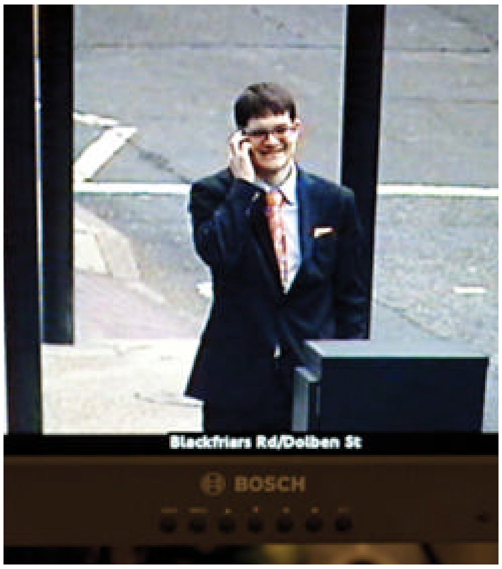
> "Not only does the new digital CCTV camera system give LSTCC far more control, but it's much faster too"

Chief engineer Brendan Sleight stands in front of the centre's main screen, although he's usually working behind the scenes

Some very clever computing facilitates all of this. Indeed, the LSTCC couldn't work without Image Recognition and Incident Detection (IRID). This highly sophisticated software can familiarise itself with road conditions and spot when something's wrong, or at least different.

TfL engineers can program specific conditions into the software that monitors a section of road, so that if those conditions are exceeded, it alerts people in the control centre. Next we are shown a busy box junction where two lanes of vehicles are waiting at traffic lights. While they're waiting, IRID is monitoring them, detecting their stationary status and visually reporting that data to the engineer via a series of grey 'x's that begin to cover the vehicles on the screen. IRID can distinguish between a street scene and a vehicle, and recognises that, say, a car is not moving. As a result, if the vehicles are there too long, then IRID will send an alert. It's a very effective and organic decision support tool for LSTCC workers.

Although digital CCTV technology has been around since the early-Nineties, London Traffic Control has only recently needed to make the wholesale upgrade to digital. The old analogue system used existing fibre-optic networks leased from third-party providers to access a camera by keying in a code from a manual. There was no multicasting: only one operator could use a camera at a time. Not only does the new digital CCTV camera system give LSTCC operators far more control, but it's much faster too. Crucially, TfL has ensured that it's open-standard and that it holds all the intellectual property rights for it, rather than buying a pay-per-view system that locks the traffic control centre into it for ever.

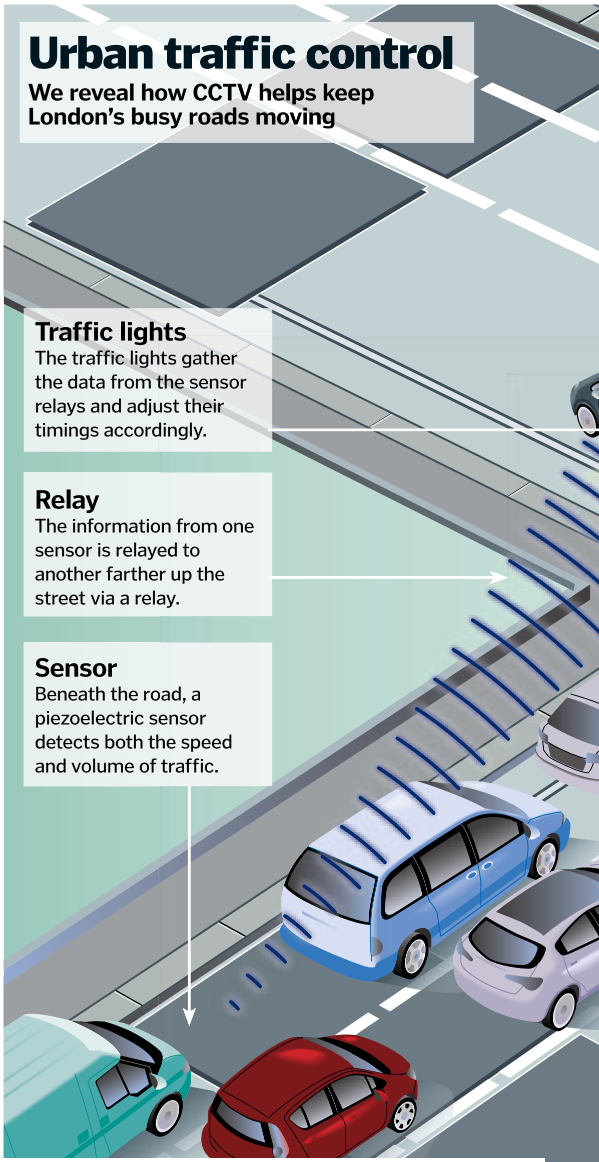


"The camera system has been developed as the technologies have changed and the strain on the network has increased," Sleight explains. "We got to 23 analogue camera matrices… and we couldn't do things like multicasting. So we finished going over to a digital system just over two years ago, so that we can actually share our cameras easily with everyone else and have multiple users looking at the same cameras [simultaneously].

"The more efficiency we can get out of the cameras the better. We can share with local ▶

## Urban traffic control

We reveal how CCTV helps keep London's busy roads moving



**Traffic lights**
The traffic lights gather the data from the sensor relays and adjust their timings accordingly.

**Relay**
The information from one sensor is relayed to another farther up the street via a relay.

**Sensor**
Beneath the road, a piezoelectric sensor detects both the speed and volume of traffic.

## Privacy masking

Privacy is a sensitive topic and the LSTCC takes it very seriously. Where there's potential for a breach of privacy, in a region where it's possible for a camera to see into someone's house, for example, the public can request the LSTCC set up an NDZ: a non-dwell zone. This is an automatic blackout point – a region of the camera covered by a black square that the operator can't see beyond. Not only that, but if the operator pans across the square, the camera will automatically keep moving through it until it's out of sight before returning control of the camera to the human. "Non-dwell zones are a security feature for the public," traffic technician Trevor Hardy tells us. "We set them up where there's a possibility of someone looking into an area where they shouldn't. The minute you look into a certain area, you can see that the camera blanks out a part of the video. It demonstrates that we have no interest in that area because there's no traffic [to monitor]."

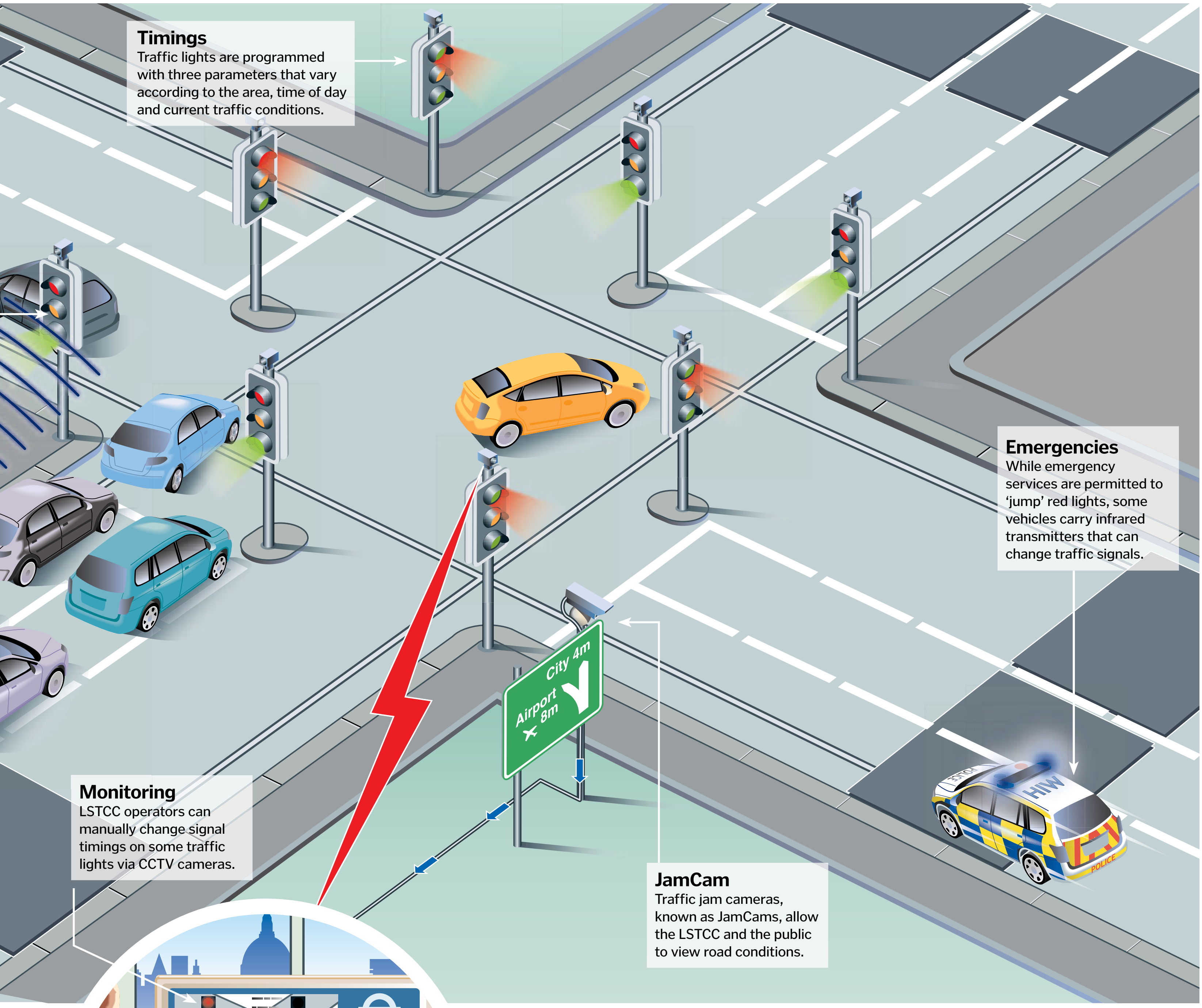
## STRANGE BUT TRUE
CCTV ORIGINS

### When was closed-circuit television first used?

**A** 1942 **B** 1972 **C** 1992

**Answer:**
Although often considered a late-20th-century invention, the very first CCTV system was used to monitor the launch of V-2 rockets in Munich, Germany, in 1942. Commercial applications for the technology didn't arrive in the US until 1949.

**DID YOU KNOW?** *The LSTCC's cameras just monitor the roads – they only record footage under exceptional circumstances*

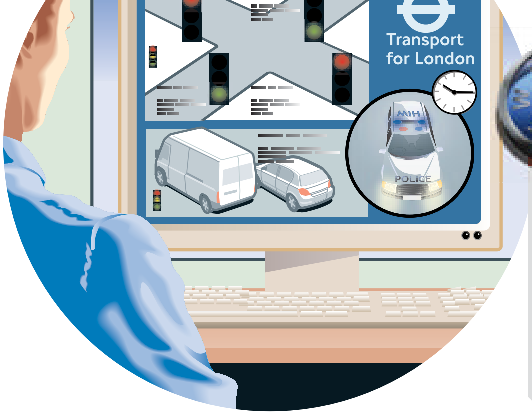


**Timings**
Traffic lights are programmed with three parameters that vary according to the area, time of day and current traffic conditions.

**Emergencies**
While emergency services are permitted to 'jump' red lights, some vehicles carry infrared transmitters that can change traffic signals.

**Monitoring**
LSTCC operators can manually change signal timings on some traffic lights via CCTV cameras.

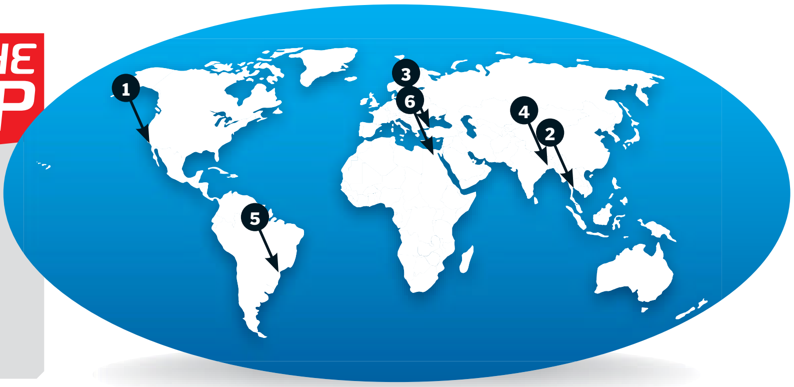
**JamCam**
Traffic jam cameras, known as JamCams, allow the LSTCC and the public to view road conditions.



## ON THE MAP

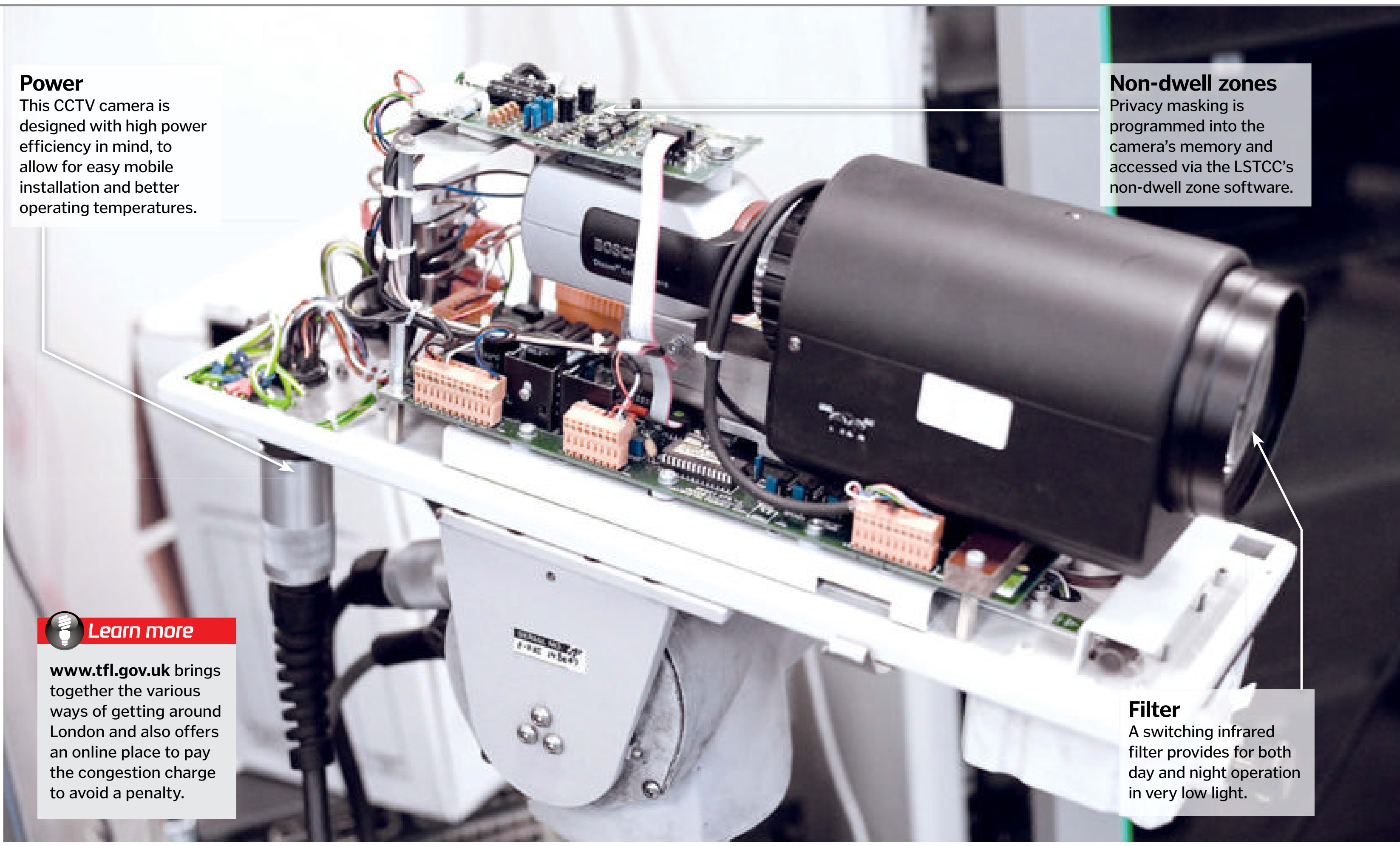
### Major cities with super-busy roads

1 Los Angeles, USA
2 Bangkok, Thailand
3 Istanbul, Turkey
4 Kolkata, India
5 São Paulo, Brazil
6 Cairo, Egypt



© NOAA; Ian Moores Graphics

> “Many authorised people can view a single camera, but only one person can control it at a given time”



**Power**
This CCTV camera is designed with high power efficiency in mind, to allow for easy mobile installation and better operating temperatures.

**Non-dwell zones**
Privacy masking is programmed into the camera's memory and accessed via the LSTCC's non-dwell zone software.

**Filter**
A switching infrared filter provides for both day and night operation in very low light.

**Learn more**

**www.tfl.gov.uk** brings together the various ways of getting around London and also offers an online place to pay the congestion charge to avoid a penalty.

boroughs, [as well as organisations] like the Metropolitan Police; they get to see our cameras so they don't have to put their own camera up and vice versa, so there's only ever one camera on site. Occasionally the police want to see different things from what TfL wants to see, but we have really good procedures for when we can ask for the camera and so do they.”

We take a look at another of the operator's screens which shows a digital street map of London peppered with icons. The technician rapidly pulls up a few different displays and shows us how, simply by clicking on an icon, he can access that particular CCTV camera. With a bit of dragging and dropping, he's transformed the monitor into a quad-screen showing four different live views of London. Another click and the entire screen has turned fish-eye, offering a broader perspective.

Many authorised people can view a single camera, but only one person can control it at a given time, so LSTCC staff can also request – or force – an override on any camera that's currently in use. Using the same system, camera faults can also be reported, as we discover when the operator hits a black screen displaying ‘Faulty CODEC’ on a camera overlooking the Purley Cross junction near Croydon. It turns out to be one of the handful of analogue cameras that TfL still has out in the wild. He immediately reports it and a technician is scrambled to the scene: “That actually normally means the site has lost power,” we're told. “A break in the cable down the pole or, more likely than not, this fault has been caused by a transmission failure from BT, which provides the analogue feed back to where we're doing the encoding. Long term we're moving the encoders all out to the street, but they've got nowhere to go at the moment.”

## Inside the lab

One of the most interesting places in the control centre is the lab. It's the LSTCC's equivalent of James Bond's Q laboratory, but much less dangerous. It's here that technicians repair cameras, find faults and try out new technologies for use in the CCTV system. A tall temporary mount allows the technicians to hang new cameras while they test them out on the internal network for their suitability. With direct access to the CCTV network and mounds of sensitive equipment lying around on workbenches in various states of repair, the lab is obviously a very secure room that only a handful of personnel have access to.

Precise planning is vital to London Traffic Control and one of the biggest tests for the LSTCC, as well as its new digital system, was the 2012 Olympics in London. Though broad systems are in place to deal with unplanned events, the LSTCC can only be reactive to a burst water pipe, a truck broken down or an accident that forces a road closure. The LSTCC had the luxury of several years' notice for 2012's Summer Olympics though. “Some of the planning started when London had the announcement, but some of it began before that because we had the visits from IOC officials and we had to make sure all their trips were smooth,” Sleight reveals. “It started in earnest four years prior to the Games and I think we had all our different shift patterns and the requirements for running control seven months in advance of the Olympics.”

London Traffic Control had three main priorities in its approach to the Games. One of them was that no official or athlete could be late for any event. Second was to minimise the

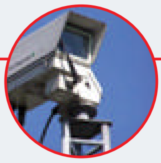
## KEY DATES

**LONDON EYE(S)**

**1960**
Two temporary video cameras are used by the police to monitor crowds in Trafalgar Square.

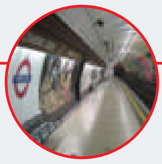
**1974**
Video surveillance systems are installed on several major roads across London.

**1989**
Civil rights activists demand more transparency on video surveillance in public places.



**2000**
Transport for London is founded, gaining most of its functions from London Regional Transport.

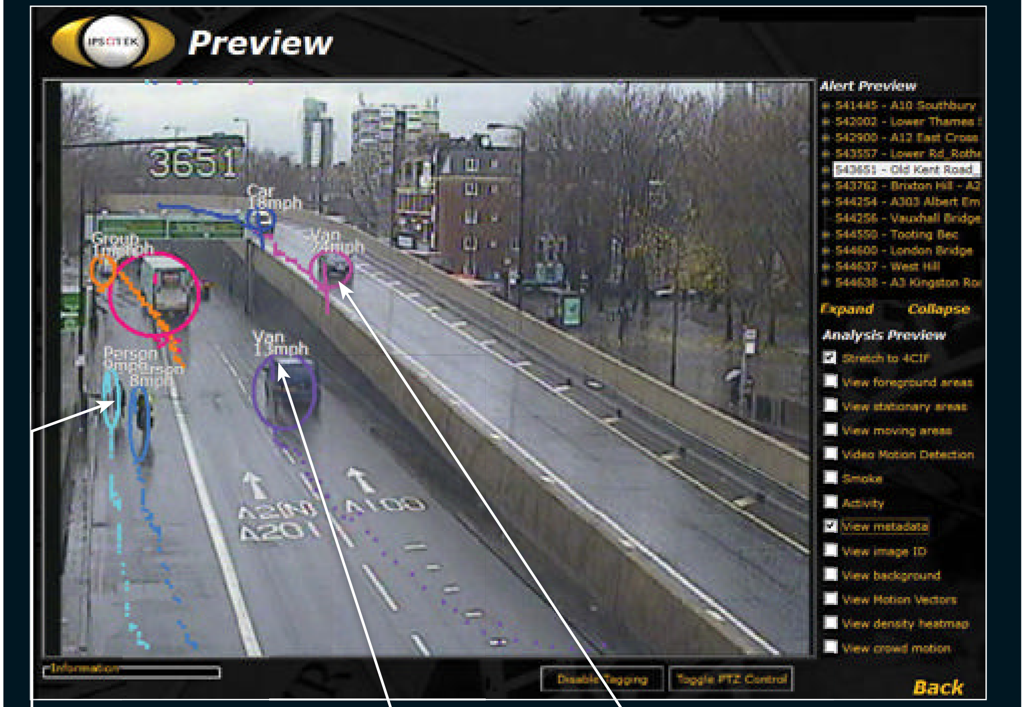
**2003**
TfL takes charge of the London Underground, bringing CCTV above and below ground.



**DID YOU KNOW?** *The average person is spotted on over 300 separate occasions by CCTV cameras each day*

## A look through the lens…

**A snapshot of what the LSTCC operators see and what each camera can detect**



**Other traffic**
Pedestrians and cyclists are recognised too – an important feature in bicycle-friendly London.

**Speed**
IRID can accurately measure the speed of a vehicle as well as the course it takes across the road.

**Vehicle type**
IRID is even able to distinguish between different basic vehicle types, helping the operator to make a more informed decision when controlling the traffic.

effect on Londoners, and third was to keep the rest of London and its businesses supplied with the transport and freight they needed to deal with the massive influx of visitors from all over the world. All three of these were achieved and, moreover – by making sure every athlete and official was on time for their respective events – the LSTCC actually achieved an Olympics first.

Looking to the future of CCTV in London, we ask whether the system will ever be fully automated. "I think we'll use the IRID system more and more to feed our intelligence," Sleight replies. "For it to say to the operator via an alert, 'I need your expertise to take a look at this'. I think we'll see more automatic alerts, but we'll still need human operators to see that it's someone who's pulled over, or a bus changing over passengers. We're always pushing the boundaries of what can be automated. We want to use the intelligence we've got to look at as many things as possible and, if we can automate some of that, that's great."

## Camera types

There are a number of different kinds of camera that London Traffic Control employs to obtain the best possible coverage of the capital. Dome cameras are a common type of CCTV camera protected by a plastic casing and installed on the corners of buildings or on telegraph poles. Outreach post cameras are mounted high up on overhanging beams to give the camera a better view of what would otherwise be a poor vantage point. Helicopter view cameras, meanwhile, provide an aerial view of a road in a very built-up area – usually they're mounted on the roof of the tallest building with permission from the owner.

Flexible deployment cameras form the mobile aspect of London's CCTV system. These typically use existing wireless or 3G networks and can run on solar power, batteries, a diesel generator or can be temporarily wired into the power supply of a traffic light system using just a tiny percentage of its voltage. These short-term cameras are used in regions where extra coverage is required for a relatively short period, such as the Olympic Games, or as a stand-in for a more permanent solution.

## London CCTV in numbers…

**913**
cameras on main CCTV system

**14,000km**
of road network coverage

**2,000**
shared cameras

**37%**
of annual congestion is caused by roadworks

**20** cameras for every road tunnel

**3,000**
urban traffic control cameras

**1 million**
car plates read per day

**500 years**
of Londoners' time is lost to congestion per year

> "For temperate and colder regions of the world, low humidity usually happens during winter"

# Humidifiers explained

We reveal the technology inside this household appliance and how it puts moisture into the air

The ideal level of humidity for our homes is around 40-50 per cent to be comfortable. If it's too low our skin and mucosal membranes can dry out, which can lead to cracks in our skin and breathing difficulties.

For temperate and colder regions of the world, low humidity usually happens during winter when very little moisture exists as vapour in the air. We talk about 'relative humidity', because warmer air can hold more water, and the air will hit saturation point (ie 100 per cent humidity) with considerably less moisture at cooler temperatures.

Humidifiers work by putting water back into the air of a room or an entire house. Using several methods they can pass $H_2O$ from a reservoir up through a filter where a fan blows the vapour into the air. A steam vaporiser boils water to release vapour, an impeller uses a diffuser to break water into droplets and releases it as a fog, while an ultrasonic humidifier vibrates a diaphragm, which also turns water into tiny droplets.

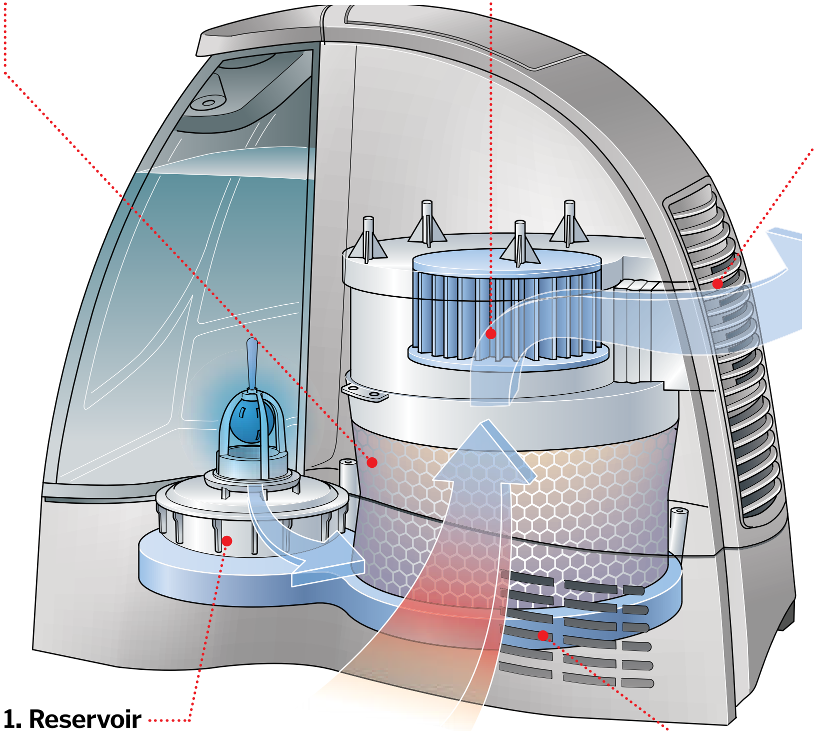
## Evaporative humidifier in action

A closer look at how the most common type of domestic humidifier works

**3. Wicking filter**
A replaceable wicking filter soaks up the water from the reservoir through its fibres.

**4. Fan**
A fan pushes the humidified air out of the vent into the room.

**5. Moist air outlet**
Moist air enters the room and raises its level of humidity via this vent.



**1. Reservoir**
A reservoir of water (sometimes distilled to remove minerals) drains into the filter.

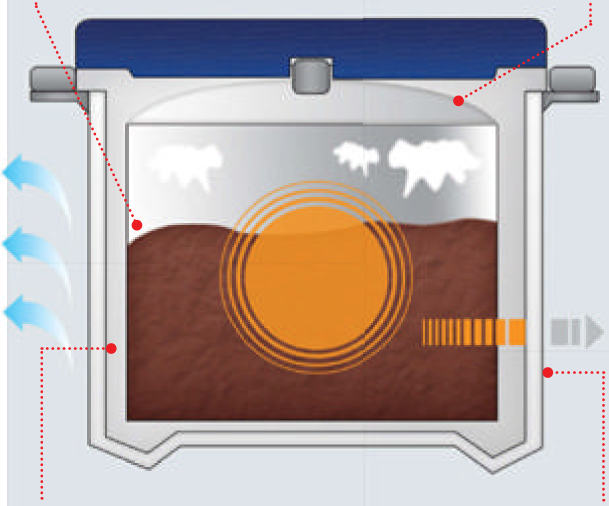
**2. Dry air inlet**
Dry air moves into the humidifier and across the wicking filter, picking up tiny water droplets.

## Inside a slow cooker

Good things come to those who wait, but what are the main components of these cooking devices?

**Internal casing**
The actual cooking pot is made of a thick ceramic material.

**Lid**
Lids can also be insulated and are necessary to keep the food from drying out while cooking.



**Vacuum cavity**
A vacuum in the double-wall cavity keeps the food hot by preventing heat conduction across it.

**External casing**
A hard outer pot protects the contents and forms the external wall of the cavity.

# How slow cookers work

How does this purveyor of tasty stews and comfort foods cook?

The electric slow cooker is based upon a centuries-old concept of heating food slowly and evenly at relatively low temperatures for long periods of time. By sealing it in the pot, the food bastes in its own juices and moisture that it releases, so tough plant and animal fibres are softened.

Electric slow cookers came along in the Seventies and comprise three main components. The outer casing is usually made of steel, designed to protect its contents and hold the heating coils between it and the inner pot in place. The inner casing is a ceramic dish that sits on the heating coils and cooks the meal. Between the inner and outer pots is a vacuum-insulated cavity, which stops heat from passing across the inner casing and so keeps the food hot – in the same way a vacuum flask can keep liquids hot for longer than an ordinary flask. Finally, a lid ensures that any moisture is sealed in.

© Peters & Zabransky

## KEY DATES
CONTACT LENSES

**1508**
Leonardo da Vinci first conceives the contact lens way back in the early-16th century.

**1887**
German physiologist Adolf Fick (right) develops the first contact lens made out of brown glass.

**1949**
The first contact lenses that rest only on the cornea, rather than the entire eye's surface, are introduced.

**1975**
Gas-permeable lenses are invented and then developed by American chemist Norman Gaylord.

**2005**
Soft and hard lenses are combined into a new hybrid, offering both comfort and durability.

**DID YOU KNOW?** Soft contact lenses are more comfortable to wear but need replacing more often than rigid lenses

# act lens ocus

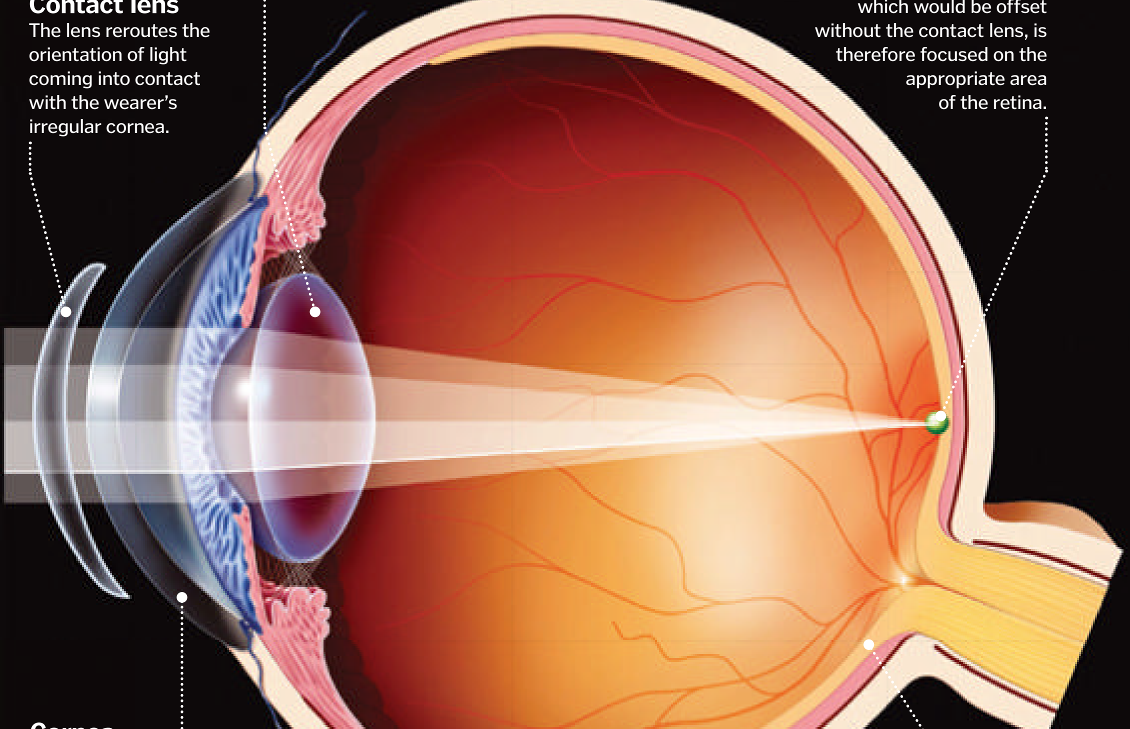
optical aids made of a hose with impaired sight?

t lenses are shaped,
gelatine polymer discs that, when
worn, correct a range of visual
deficiencies. These include astigmatisms (non-uniform cornea or crystalline lens curvature), myopia (nearsightedness) and hyperopia (farsightedness). They achieve this by modifying image focusing on the wearer's retina, which is typically out of alignment.

Contact lenses are made in a rapid yet
a user's prescription
mine the lens shape,
his data is entered
igital lathe, capable of
nute. The lathe is fed a
lpts out what will be
– ie the part that
is then polished with
easured for thickness.
lathe for outer
h the diamond tip
ers of polymer at a
s then coated with oil
gh rims are polished.
rrect shape and power
to be hydrated. It is
saline solution for 24
es the polymer gelatine
d expanding.
ed for quality and
topographer machine,
read of optical power
frontal focal meter,
cision of the lens
s prescription. ✪

## How contact lenses correct astigmatisms

**Check out this cross-section for a clearer idea of how contacts can improve impaired vision**



**Crystalline lens**
If the user suffers lenticular astigmatism – misalignment of the lens – the contact lens rights this in the same way as the cornea.

**Focal point**
The focal point of the light, which would be offset without the contact lens, is therefore focused on the appropriate area of the retina.

**Contact lens**
The lens reroutes the orientation of light coming into contact with the wearer's irregular cornea.

**Cornea**
The cornea receives the light in the correct orientation for the irregular surface to accurately transmit it deeper into the eye.

**Retina**
With light rays focused correctly, the retina can receive and process a clear and sharp image, which is delivered via nerve impulses to the brain.

© Getty; Thinkstock

Personal CNC for Home or Hobby

Don't Let Your Tools Hold Back Your Creativity

Tormach Personal CNC machines are the ultimate workshop tool. Whether you're a jeweler, artist, prototype builder, engineer, model maker or hobbyist, a Tormach PCNC will expand your possibilities and enable your ideas.

The PCNC 1100 Features:

- 3-Axis CNC Milling Machine cuts aluminum, steel, plastic, wood and more
- Table size 26" x 8"
- 5000 RPM computer-controlled spindle
- Stiff cast iron frame
- Space-saving footprint
- Requires single-phase 230VAC 50/60Hz electrical service
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*Steel Clutch Plate for Reproduction Case 65 Steam Traction Engine machined with the PCNC 1100*

*Shown here with optional stand, LCD monitor, machine arms, and accessories.*

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> "G-Cans was built to protect Tokyo City from flooding, which it is prone to during typhoon season"

# The world's biggest drain

## What does the planet's largest subterranean flood diversion facility do and why does it need to be so big?

Shutoken Gaikaku Housui Ro, otherwise known as G-Cans or the Metropolitan Area Outer Underground Discharge Tunnel, is essentially the world's largest drain. It can be found underground between the Showa region of Tokyo, Kasukabe in Saitama prefecture and the outskirts of Tokyo City. Loosely speaking it performs the same function as a standard drain – that hole in the road with a metal grille over the top that we encounter every day, which ultimately diverts excess surface water to avoid flooding. But it's on a totally different scale and much more sophisticated than that.

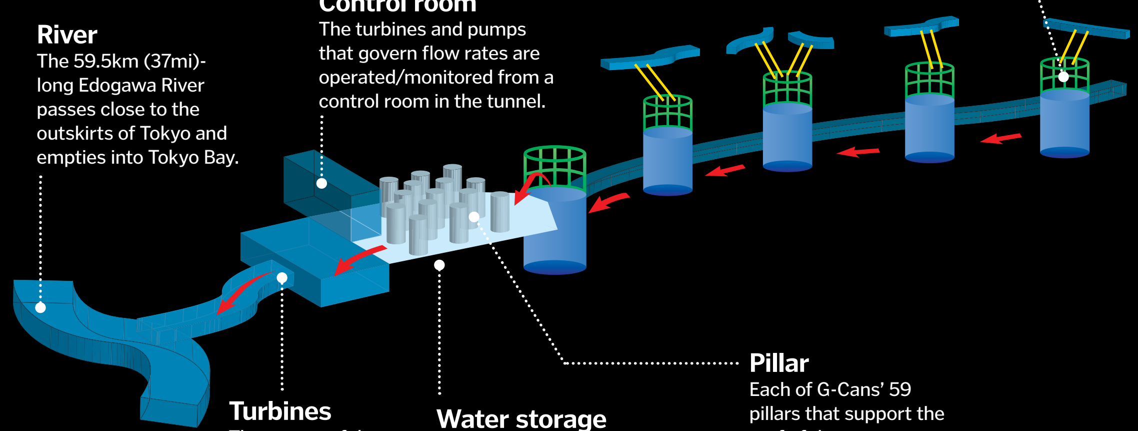
Five enormous silos, each 65 metres (213 feet) deep and 32 metres (105 feet) wide are spaced at regular intervals, within a certain distance from Tokyo's main rivers, including the Oochi Kotone, Kuramatsu, Arakawa and Nakagawa. They're connected by 6.5 kilometres (four miles) of tunnels 11 metres (35 feet) high and 50 metres (164 feet) under the ground that act as a flow regulator for floodwater. The real show-stopper though has to be the water storage tank into which this tunnel network empties.

The storage tank – aka the 'Underground Temple' – is a marvel of engineering. 177 metres (580 feet) long and 25 metres (83 feet) tall, it's supported by 59 pillars and connected to 78 pumps. These in turn connect to ten-megawatt (14,000-horsepower) turbines that are monitored by a control room also located in the tunnel. These turbines enable G-Cans to pump tons of water out on a safer course farther upstream.

G-Cans was built to protect Tokyo City from flooding, which it is particularly prone to during typhoon season. This facility channels surface floodwater that can't be handled by the normal drainage system into the silos and then out to the Edogawa River on the outskirts of the city. ✱

## Where does all the water go?

**Follow the path that floodwater takes under one of the world's busiest cities...**



**Silo**
Each of the silos can hold over 5 million litres (1.3 million gallons) of water.

**Control room**
The turbines and pumps that govern flow rates are operated/monitored from a control room in the tunnel.

**River**
The 59.5km (37mi)-long Edogawa River passes close to the outskirts of Tokyo and empties into Tokyo Bay.

**Pillar**
Each of G-Cans' 59 pillars that support the roof of the storage area is 20m (65.6ft) tall and weighs 500 tons.

**Turbines**
These powerful turbines can pump up to 200 tons a second from the water storage out into the Edogawa River.

**Water storage**
The water storage facility itself is little more than an enormous chamber with the capacity to hold thousands of tons of water.

**RECORD BREAKERS**

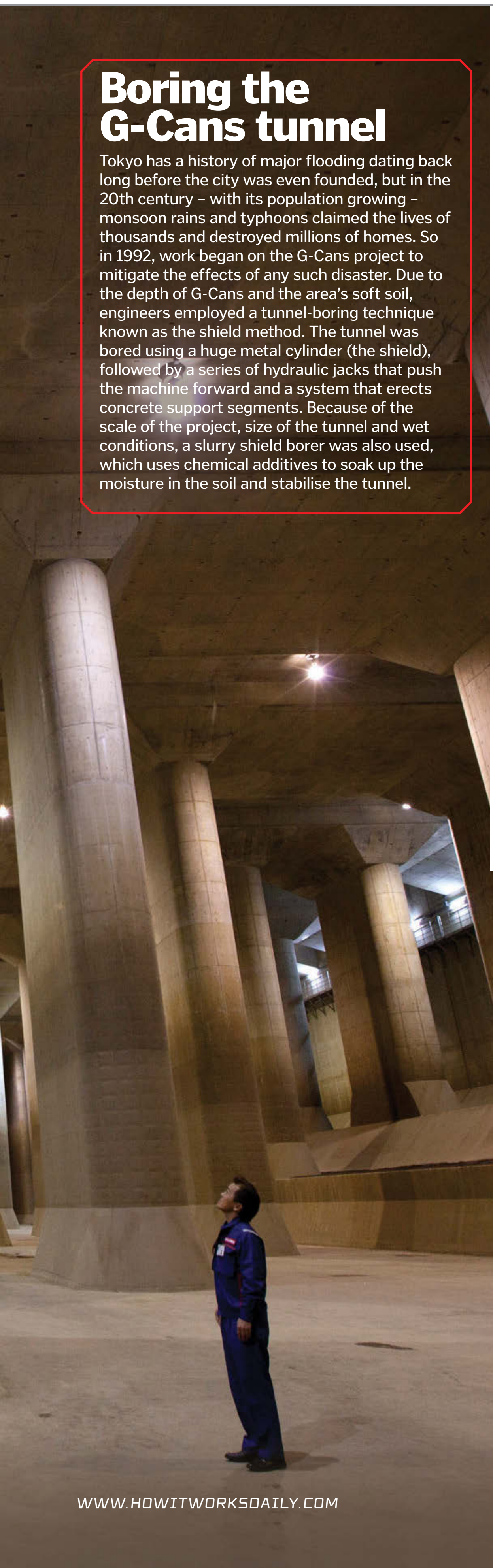
**WASHINGTON WASHOUT**

**17mn m³**

## EARTH'S BIGGEST-EVER FLOOD

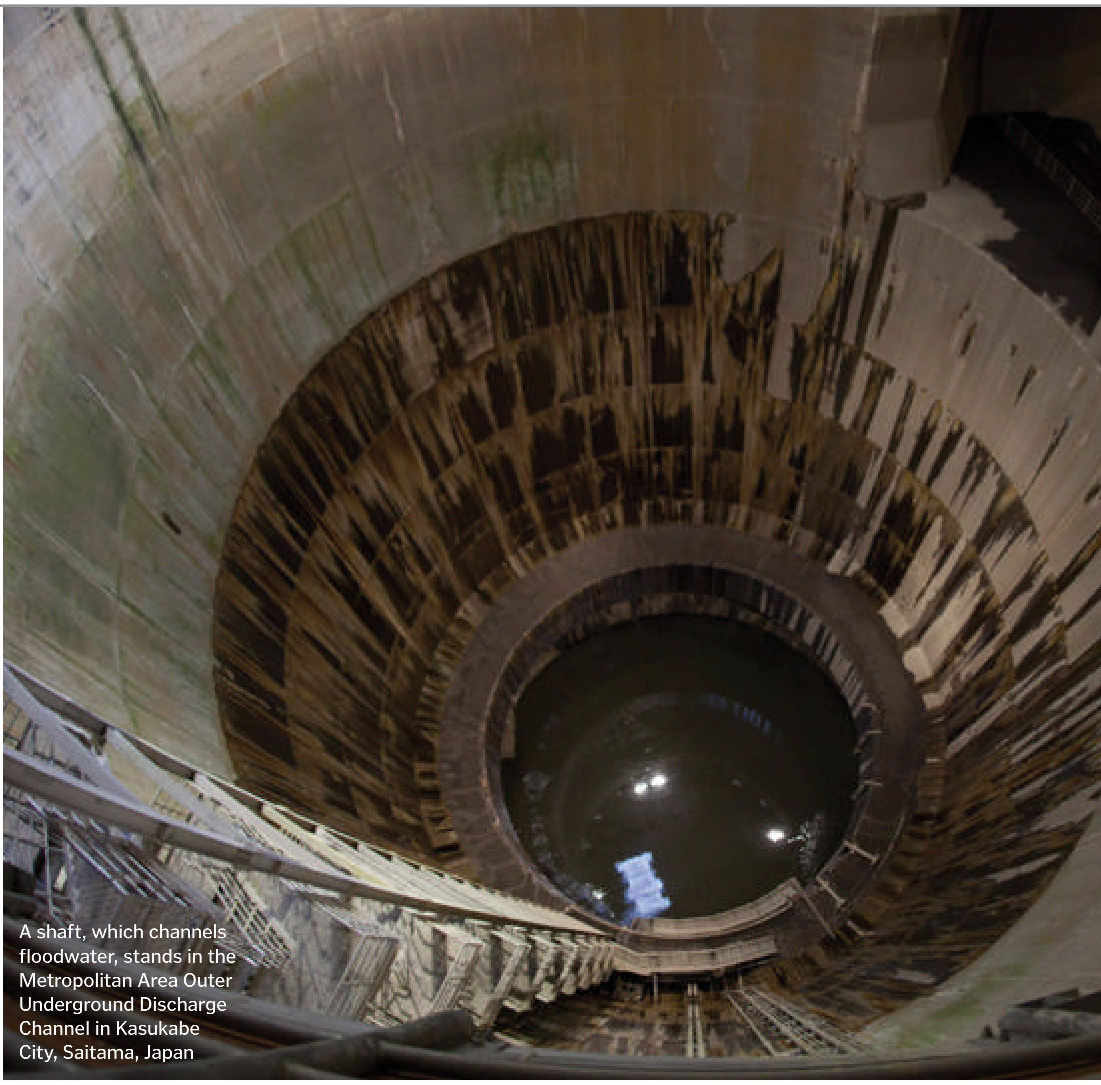
About 17 million cubic metres (600 million cubic feet) of water gushed out of an ice dam every second when a glacier burst by the Clark Fork River in the last ice age, sweeping over Oregon and Washington State.

**DID YOU KNOW?** *The water storage tank is often called the Underground Temple due to its cathedral-like appearance*



## Boring the G-Cans tunnel

Tokyo has a history of major flooding dating back long before the city was even founded, but in the 20th century – with its population growing – monsoon rains and typhoons claimed the lives of thousands and destroyed millions of homes. So in 1992, work began on the G-Cans project to mitigate the effects of any such disaster. Due to the depth of G-Cans and the area's soft soil, engineers employed a tunnel-boring technique known as the shield method. The tunnel was bored using a huge metal cylinder (the shield), followed by a series of hydraulic jacks that push the machine forward and a system that erects concrete support segments. Because of the scale of the project, size of the tunnel and wet conditions, a slurry shield borer was also used, which uses chemical additives to soak up the moisture in the soil and stabilise the tunnel.



A shaft, which channels floodwater, stands in the Metropolitan Area Outer Underground Discharge Channel in Kasukabe City, Saitama, Japan

## Tokyo floods

Located next to Tokyo Bay in the Kanto region of central Honshu – and with over 13 million inhabitants – Tokyo spans the alluvial floodplain of three major rivers in the area. The Edogawa and Arakawa Rivers meander around Tokyo's outskirts, while the Sumida River flows right through the centre. When the weather is relatively dry in springtime and late autumn/winter, living in one of the many regions of Tokyo that lie below the flood level isn't a problem. But the rainy season (or *tsuyu*) hits Japan in June and July, while typhoon season peaks in late-August through to October. A major part of Japan's annual average 1,800 millimetres (70.9 inches) of precipitation occurs during these months and devastating flash floods, as well as tidal surges brought on by terrible typhoon winds, can sometimes wreak havoc on communities – even with the additional flood protection afforded by G-Cans.

© Bloomberg via Getty

*"The Wii U is the first Nintendo console to feature full high-definition graphics"*

# Exploring the Wii U

## What technology goes into Nintendo's newest console? How It Works lifts the lid to find out…

The latest games console from Nintendo is the first in what is considered the eighth generation, which all began with the Magnavox Odyssey and Atari's Pong home console in the Seventies.

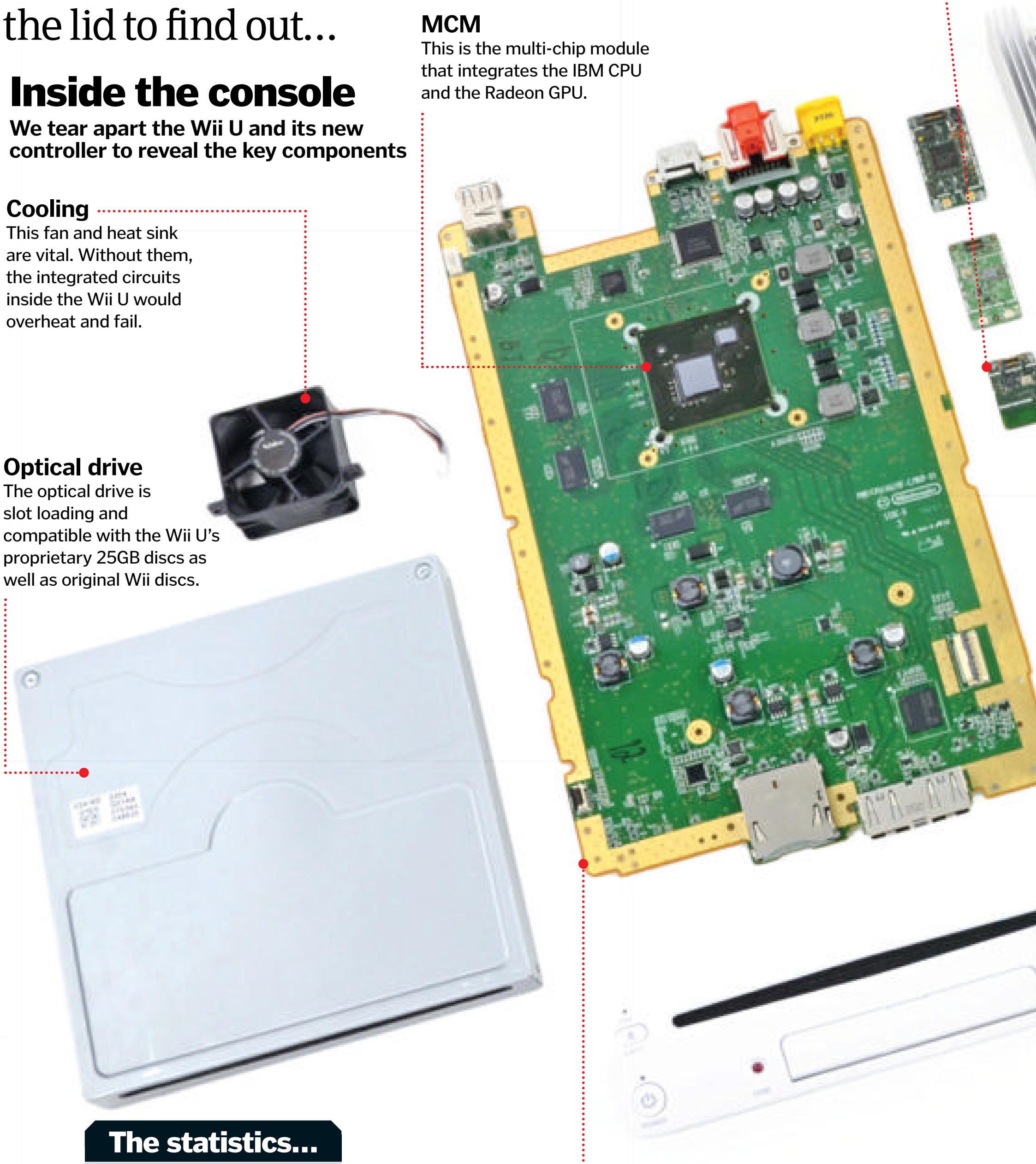
There are two main parts to the new console: the box with the Wii U optical disc drive that forms the traditional console hub, and the very non-traditional peripheral Wii U GamePad.

The hub contains the main components and is the first Nintendo console to feature full high-definition graphics, with an output supporting up to 1080p resolution. The basic version of the Wii U features a fairly limited eight gigabytes of internal flash memory, but it's expandable with USB hard drives up to two terabytes – an ample maximum capacity for the game downloads, video storage and more that you're able to save on this machine.

It has a 45-nanometre, multi-core IBM CPU architecture – around half the manufacturing process size of the CPU in its predecessor (the Wii), which results in much greater processing efficiency. It has two gigabytes of DDR3 RAM – the 'memory' of the Wii U used for the dynamic storage of fast processes. Finally, its graphics processing unit (GPU) is based on AMD's Radeon technology, with bespoke video output for the Wii U. Interestingly, both the CPU and GPU are compiled onto one multi-chip module (MCM), creating a single integrated circuit that processes more quickly and, vitally, takes up less of the console's limited internal space.

## Inside the console

**We tear apart the Wii U and its new controller to reveal the key components**



**Cooling**
This fan and heat sink are vital. Without them, the integrated circuits inside the Wii U would overheat and fail.

**Optical drive**
The optical drive is slot loading and compatible with the Wii U's proprietary 25GB discs as well as original Wii discs.

**MCM**
This is the multi-chip module that integrates the IBM CPU and the Radeon GPU.

**Wireless**
These are the three Broadcom wireless modules that allow the Wii U to communicate across a LAN, Bluetooth 4.0 and 802.11n standard.

**Console motherboard**
All the major components of the Wii U (CPU, RAM, etc) are brought together on this circuit board.

### The statistics…

#### Wii U console

**Dimensions:** 26.7 x 17.2 x 4.5cm (10.5 x 6.8 x 1.8in)

**Weight:** 1.6kg (3.5lb)

**Output:** Up to 1,920 x 1,080px

**Internal memory:** 8GB (basic); 32GB (deluxe)

#### Wii U GamePad

**Dimensions:** 25.9 x 13.5 x 2.3cm (10.2 x 5.3 x 0.9in)

**Weight:** 491g (1.1lb)

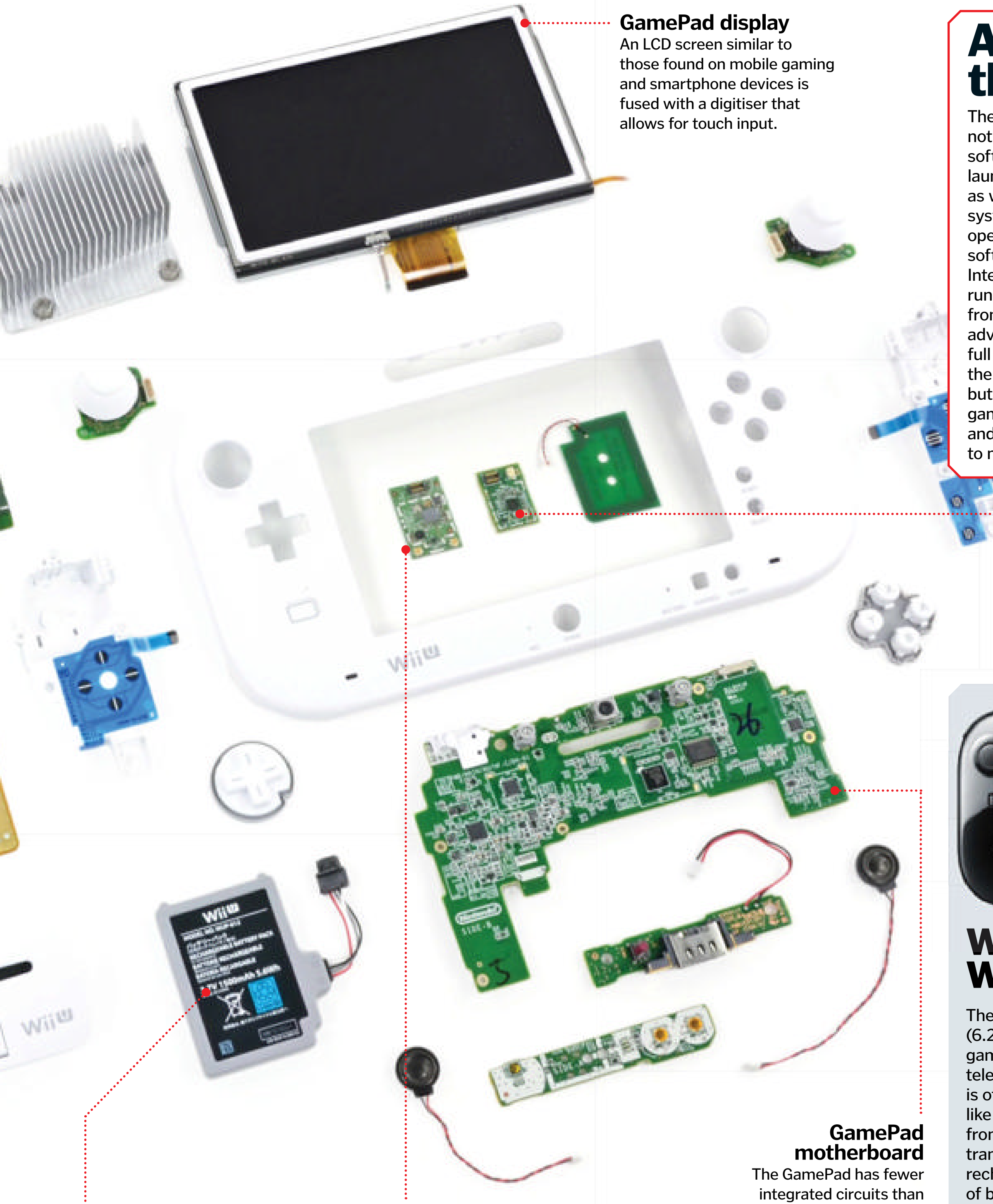
**STRANGE BUT TRUE**
**RETRO GAMER**

## When was the Nintendo company founded?

**A** 1889 **B** 1951 **C** 1980

**Answer:**
Incredibly, Nintendo was founded in Japan as a card company as long ago as 1889. It was primarily a playing card manufacturer until it expanded into the electronic toy industry in the Sixties, turning its hand to videogames in the Seventies.

**DID YOU KNOW?** *It will be possible to pay for Nintendo Network downloads by placing an NFC credit card on the GamePad*



### GamePad display
An LCD screen similar to those found on mobile gaming and smartphone devices is fused with a digitiser that allows for touch input.

### NFC board
This is the GamePad's near-field communications board. It's currently unused but Nintendo has interesting plans for its future to enable quick-and-easy purchases.

### GamePad motherboard
The GamePad has fewer integrated circuits than the console, but still needs a hub to plug them all into.

### Battery
The Wii U GamePad has a rechargeable 3.7V battery that lasts between three and five hours depending on display brightness.

### Wireless module
This module is used to communicate between the Wii U console and GamePad controller over a 5,150-5,250MHz frequency.

## A spotlight on the software

The most powerful consoles in the world are nothing without adequate support from the software developed for them. The games launcher, the Nintendo Network and its features, as well as Nintendo's bespoke social network system, Miiverse, all sit on top of the Wii U operating system. It's a piece of proprietary software that Nintendo has code-named IOS – Internal Operating System – and, unusually, it runs using a dedicated ARM-based CPU separate from the IBM CPU used by game software. The advantage of this is that the Wii U can utilise the full processing capacity of its main CPU to tackle the most power-intensive games. Not only that, but unlike PCs and many other consoles, while a game is running, the Wii U can switch the IOS off and unload it from memory, allowing the game to make full use of the system RAM.

## What's new with the Wii U GamePad?

The GamePad has an embedded 15.7-centimetre (6.2-inch) touchscreen that complements gameplay when the Wii U outputs to the television, and can be played even when the TV is off. It has many independent functions too, like stereo speakers and mic, volume control, a front-facing camera, infrared sensor strip and transceiver, wireless communications, rechargeable battery pack and, of course, lots of buttons. On top of this, it includes a near-field communications (NFC) chip that enables users to import content from supported devices simply by placing them onto the pad.

The Wii U GamePad is a far more sophisticated piece of kit than any console controller in history and can almost be considered a separate console in itself. Nintendo has made the device deliberately large and comprehensively featured to take the player's attention from the main console, which it refers to as the 'stagehand' – in other words, something that works unnoticed but plays an important role behind the scenes.

© iFixit.com; Eckhard Pecher; Nintendo

# Walking in space

Spacewalks are one of the most dangerous pursuits performed by astronauts, with each one requiring technical skill, advanced technology and nerves of steel

**RECORD BREAKERS**
**GOING THE DISTANCE**

**100m**

## FARTHEST SPACEWALK

100 metres (328 feet) is the greatest distance any astronaut has ventured from a spacecraft during an untethered spacewalk – a record achieved by US astronaut Bruce McCandless II in 1984.

**DID YOU KNOW?** *Cosmonaut Anatoly Solovyev holds the record for most number of spacewalks performed – 16*

From spacecraft repairs to conducting experiments in an off-Earth environment, EVAs are a vital part of space exploration

Spacewalks – which are technically referred to as extravehicular activities (EVAs) – are characterised as any activity performed by an astronaut outside the protected environment of a spacecraft's cabin.

Each EVA is conducted by an astronaut in a specialised spacesuit called an extravehicular mobility unit (EMU), which unlike the spacecraft's cabins use 100 per cent pure oxygen instead of air. The use of pure oxygen is necessary as the EMU suit is pressurised to one-third of atmospheric pressure, and at that level the quantity of oxygen in air is insufficient. The oxygen in each EMU suit comes courtesy of two tanks located on its back.

Due to the duration of a typical modern EVA ranging from four to eight hours, the EMU is also equipped with an internal 0.9-kilogram (32-ounce) drink bag and valved drink tube. The valve is automatically opened when the astronaut sucks on the tube, allowing hands-free access to water. For particularly lengthy spacewalks, the EMU can also be equipped with a nutrient food bar, accessible on a suit-mounted strut.

In addition to an EMU suit, most EVAs today are also undertaken with a simplified aid for EVA rescue (SAFER) exoskeleton unit. This piece of cutting-edge equipment is secured to the EMU's backpack via a waist-mounted connector and acts as an emergency propulsion system should the astronaut become separated from the spacecraft or robotic arm platform during a spacewalk. The system works, when activated, by directing nitrogen gas through a series of nozzles into the surrounding void of space, generating small, adjustable jets of the gas that can be used to propel the astronaut in a range of directions.

Each EVA begins in the spacecraft's airlock, which is directly vented of its atmosphere ▶

## Five amazing facts about: spacewalks

### 1 Not for everyone

While more than 500 astronauts have been in space over the past 50 years, only just over 200 of them have actually performed a spacewalk or moonwalk.

### 2 The waiting game

Once an astronaut is securely in their EVA suit, they can't immediately go out into space, but instead must spend an hour acclimatising to the pressure in the airlock.

### 3 Loaded

As of 2012 seven space tourists have paid £15.5 million ($25 million) each to be transported to the ISS, spend a week on board and perform a spacewalk.

### 4 Cutting the cord

For untethered spacewalks a special EVA suit is used, known as a manned manoeuvring unit (MMU). These use a variety of gaseous nitrogen nozzles to propel the wearer about.

### 5 Elite

To date the only space agencies that have successfully demonstrated an ability to conduct spacewalks are NASA (USA), CNSA (China) and the FKA (Russia).

"The vast majority of spacewalks are performed to carry out spacecraft repair or maintenance"

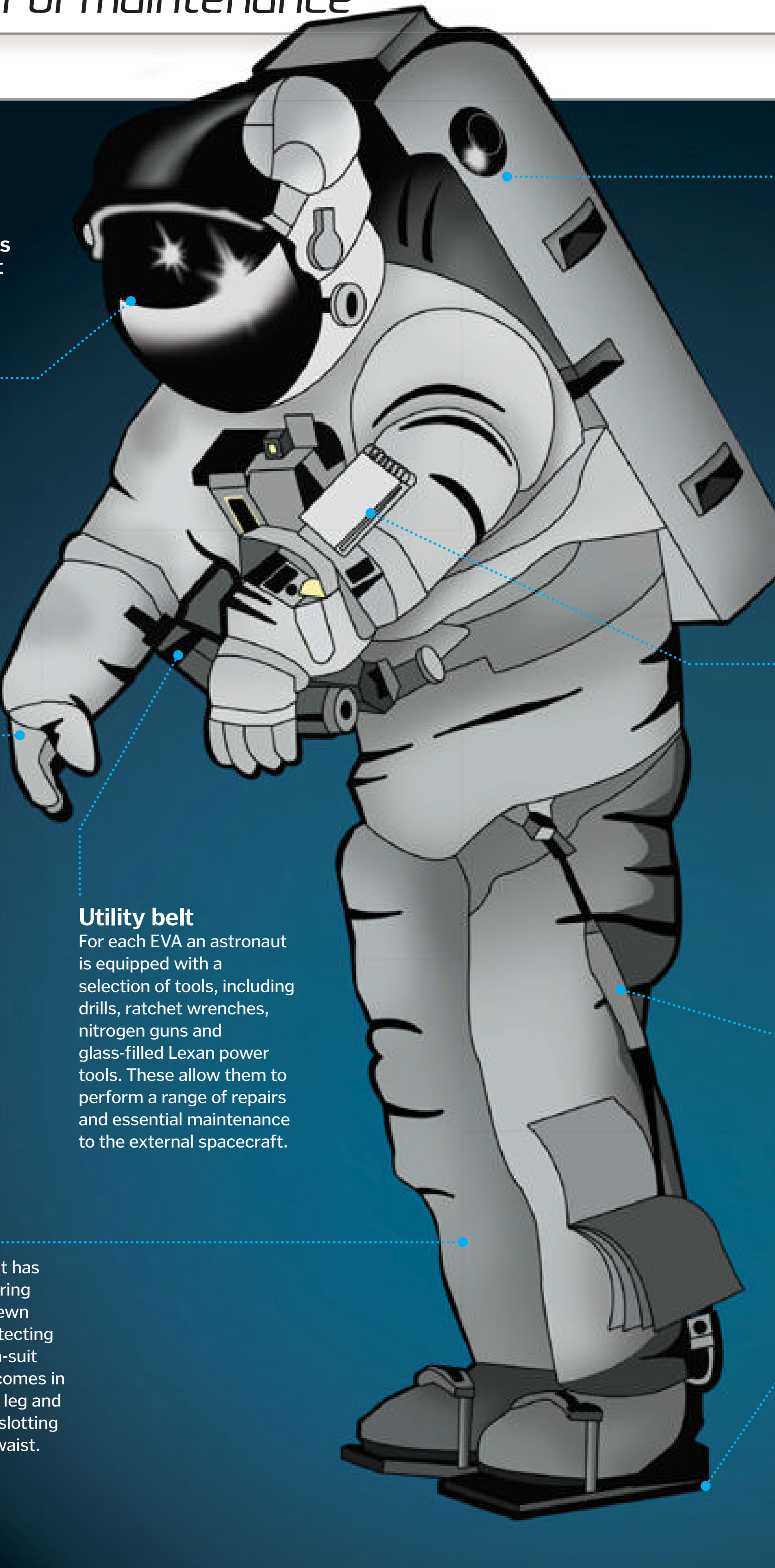
once the astronaut is suited and acclimatised. This process reduces the airlock's pounds per square inch absolute (psia) pressure from 14.7 psia down to around 1-2 psia. Once this is achieved, the external airlock door is released.

The vast majority of spacewalks are performed to carry out spacecraft repair or maintenance and, as such, involve the astronaut taking along a selection of tools with them. These tools, which include drills, ratchet wrenches, nitrogen guns and adapted power tools to name just a few, are tethered to the EMU via twin-release action cords. These ensure that the tools stay secured at all times during the operation and also allow the astronaut's hands to remain free for manoeuvring around the spacecraft.

To date, over 200 spacewalks have been performed, with most occurring during the construction of the International Space Station (ISS). The most recent spacewalk was conducted by American astronaut Sunita Williams and Japanese astronaut Akihiko Hoshide on 1 November 2012. This EVA was undertaken to isolate a leak in the ISS's power channel ammonia cooling system. The team successfully fixed the leak, spending a total of six hours 38 minutes walking in space. ✿

## The key kit

**We break down a modern EVA suit to see which tools are taken on a space jaunt**



**Helmet**
This protects against harmful light rays and contains a set of headlights and television cameras. Due to the long periods of time astronauts spend on EVAs these days, there's also an internal water hose so that the astronaut can drink.

**Glove**
EVA spacesuit gloves have thumb and fingertips moulded from silicone rubber for sensitivity and enhanced grip. Internal heaters in the fingertips prevent the astronaut's digits from getting cold and turning numb.

**Utility belt**
For each EVA an astronaut is equipped with a selection of tools, including drills, ratchet wrenches, nitrogen guns and glass-filled Lexan power tools. These allow them to perform a range of repairs and essential maintenance to the external spacecraft.

**Suit**
An EVA spacesuit has 14 layers of differing materials with sewn channels for protecting and regulating in-suit temperature. It comes in two pieces, with leg and torso segments slotting together at the waist.

## No walk in the park...

There are myriad dangers that an astronaut might encounter when performing a spacewalk. Indeed, far from merely having to contend with the likely fatal effects of their spacesuit being compromised (ie depressurised), there are also the risks presented by temperature extremes and astro-collisions.

Taking temperature as the first example, any object that is lit directly by the Sun outside of Earth's atmosphere will be heated to over 120 degrees Celsius (248 degrees Fahrenheit), while any object not lit will see its temperature plummet to below -100 degrees Celsius (-148 degrees Fahrenheit). As such, while the astronaut's suit can protect them to some extent from these extremes, they still have to be wary about remaining in one position for an extended period of time.

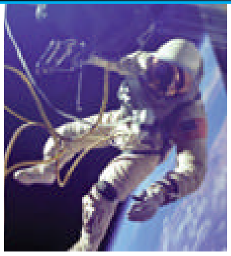
Moving on to the second example, astro-collisions can be caused by tiny meteoroids, the spacecraft itself and even man-made debris orbiting Earth which has broken off old satellites etc. Impacting the spacecraft can lead to the astronaut breaking free of their tether and damaging key systems, while being hit by a meteoroid or piece of space junk can rupture the suit and even ricochet them out into space.

## History of spacewalks

**Follow the development of humankind's journey into space over the last 50 years with these noteworthy missions**

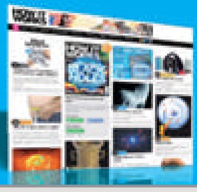
### 1965
**Voskhod 2**
In March 1965 Aleksei Leonov becomes the first person in history to perform a spacewalk. It lasts 12 minutes.

### 1965
**Gemini 4**
A couple of months after Voskhod 2, Edward White is the first American to perform a spacewalk. It lasts for 21 minutes.



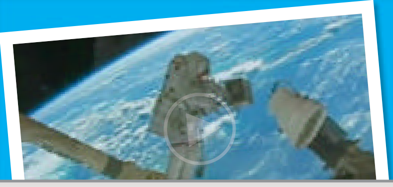
### 1971
**Apollo 15**
American astronaut Alfred Worden carries out the first-ever deep-space EVA during the return journey of Apollo 15 from the Moon.

### 1984
**STS-41B**
Three years after the robotic Canadarm was launched, astronaut Robert Stewart becomes the first person to use it as a spacewalk platform.



**AMAZING VIDEO!** SCAN THE QR CODE FOR A QUICK LINK

**Hear about the odd sensations on a spacewalk**



**DID YOU KNOW?** *Spanish-American astronaut Michael López-Alegría holds the record for spacewalks per mission – 5*

**Backpack**
For modern EVAs, astronauts are equipped with a SAFER backpack system. This is an exoskeleton that allows propulsion through space via a series of nitrogen gas-firing nozzles. It acts as a backup system if the astronaut should ever become separated.

**Notepad**
Externally mounted to one of the astronaut's arms is a simple notepad and space-pen. This enables astronauts to jot things down while on an EVA without having to worry about losing either while performing manoeuvres.

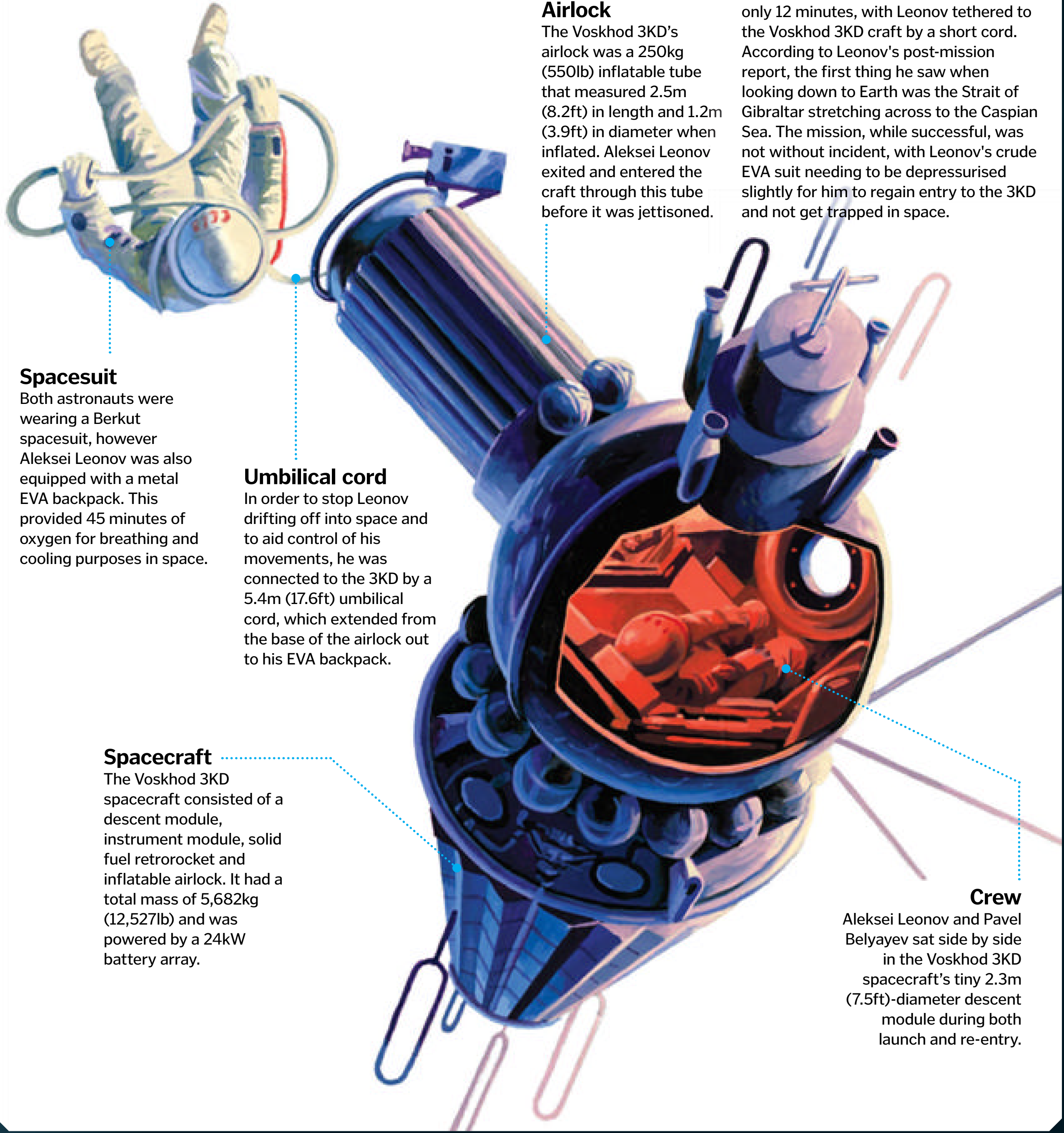
**Harness**
The first and most fail-safe system to keep astronauts linked to the spacecraft or robotic arm is a clip harness. This attaches to the astronaut's utility belt.

**Platform**
While astronauts do perform detached EVAs, the majority today are undertaken from the end of a robotic arm (such as the Canadarm2). Astronauts hook their feet into a special platform to remain securely attached.

# The first spacewalk in focus

**We break down the techniques and technology that led to the first human stepping into the void**

Voskhod 2 was a manned Soviet space mission in 1965 in which Aleksei Leonov became the first ever person to leave a spacecraft in a specialised suit and perform a spacewalk. The walk lasted only 12 minutes, with Leonov tethered to the Voskhod 3KD craft by a short cord. According to Leonov's post-mission report, the first thing he saw when looking down to Earth was the Strait of Gibraltar stretching across to the Caspian Sea. The mission, while successful, was not without incident, with Leonov's crude EVA suit needing to be depressurised slightly for him to regain entry to the 3KD and not get trapped in space.



**Airlock**
The Voskhod 3KD's airlock was a 250kg (550lb) inflatable tube that measured 2.5m (8.2ft) in length and 1.2m (3.9ft) in diameter when inflated. Aleksei Leonov exited and entered the craft through this tube before it was jettisoned.

**Spacesuit**
Both astronauts were wearing a Berkut spacesuit, however Aleksei Leonov was also equipped with a metal EVA backpack. This provided 45 minutes of oxygen for breathing and cooling purposes in space.

**Umbilical cord**
In order to stop Leonov drifting off into space and to aid control of his movements, he was connected to the 3KD by a 5.4m (17.6ft) umbilical cord, which extended from the base of the airlock out to his EVA backpack.

**Spacecraft**
The Voskhod 3KD spacecraft consisted of a descent module, instrument module, solid fuel retrorocket and inflatable airlock. It had a total mass of 5,682kg (12,527lb) and was powered by a 24kW battery array.

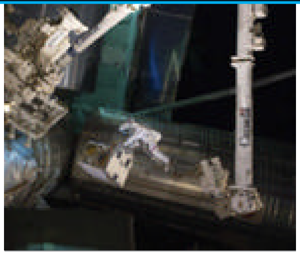
**Crew**
Aleksei Leonov and Pavel Belyayev sat side by side in the Voskhod 3KD spacecraft's tiny 2.3m (7.5ft)-diameter descent module during both launch and re-entry.

## 1984
**STS-41B**
American astronaut Bruce McCandless II travels 100 metres (328 feet) away from the Challenger shuttle using an MMU.

## 1992
**STS-49**
Following the functional loss of the INTELSAT VI satellite in 1990, three astronauts perform the longest spacewalk to date to recapture it.

## 1994
**STS-64**
Astronaut Mark Lee tests the follow-up to the MMU, the SAFER suit, making a sustained spacewalk around the Discovery shuttle.

## 2011
**STS-135**
Michael Fossum and Ronald Garan carry out the last spacewalk of the Space Shuttle programme and the 160th in the construction of the ISS.



© NASA; Thinkstock

> "A slight dip in their brightness might occur if a planet orbiting close to the star passes between it and Earth"

# What are variable stars?

## Why do these celestial bodies fluctuate in luminosity and what makes them so important to astronomy?

The definition of a variable star is simply a stellar body whose apparent magnitude (ie its brightness seen from Earth) changes – usually in a regular cycle. Broadly speaking, these can be divided into two categories: stars with intrinsic variation whose brightness actually varies because of its own physical makeup, and extrinsic variable stars whose variation is caused by other objects affecting the amount of light reaching Earth.

These two types can be further divided into dozens of subcategories. Intrinsic examples include Cepheids and Cepheid-like stars, a type of pulsating variable star, often with a regular cycle. Eruptive variables experience changes in luminosity due to mass ejections or stellar eruptions on their surface so violent that the surge in energy output can be seen as a peak in apparent magnitude. Cataclysmic variables, meanwhile, can be considered the extreme end of eruptive variables, where the properties of the star are irrevocably changed as a result of a cataclysmic event, such as a nova or supernova.

Extrinsic variables, on the other hand, can be categorised into two main types. Rotating variables include stars that exhibit changes in luminosity because brighter and darker areas of their surface move in and out of view as they spin. This can be the result of a cluster of stellar spots or changes in the magnetic field over specific parts of the body's surface. Eclipsing variables, meanwhile, often have a companion binary star that blocks some of its neighbour's light when viewed from a certain angle.

A slight dip in their brightness might occur if a planet orbiting close to the star passes between it and Earth, such as exoplanet candidate UCF-1.01. This was discovered by NASA's Spitzer Space Telescope in July 2012 orbiting the red dwarf GJ 436. ✽

Variable stars are hugely useful to astronomers for calculating distances, learning how stellar bodies evolve and potentially even finding new planets that could support life

# HEAD2HEAD
## BRIGHT BODIES

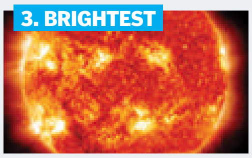
**1. BRIGHT**

**Sirius**
8.6 light years away, this is the brightest star in the night sky with an apparent magnitude of -1.5 (note: lower numbers are actually brighter).

**2. BRIGHTER**

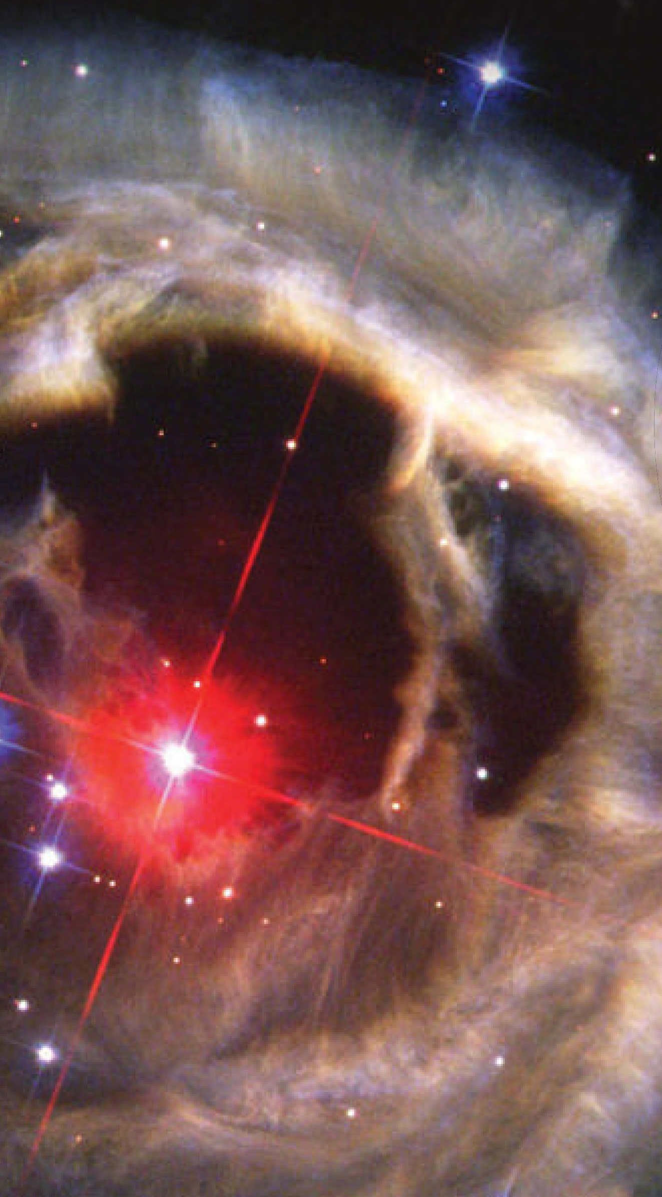
**The Moon**
The second-brightest object in the sky is our very own Moon, reflecting light from the Sun. Its apparent magnitude measures in at -12.6.

**3. BRIGHTEST**



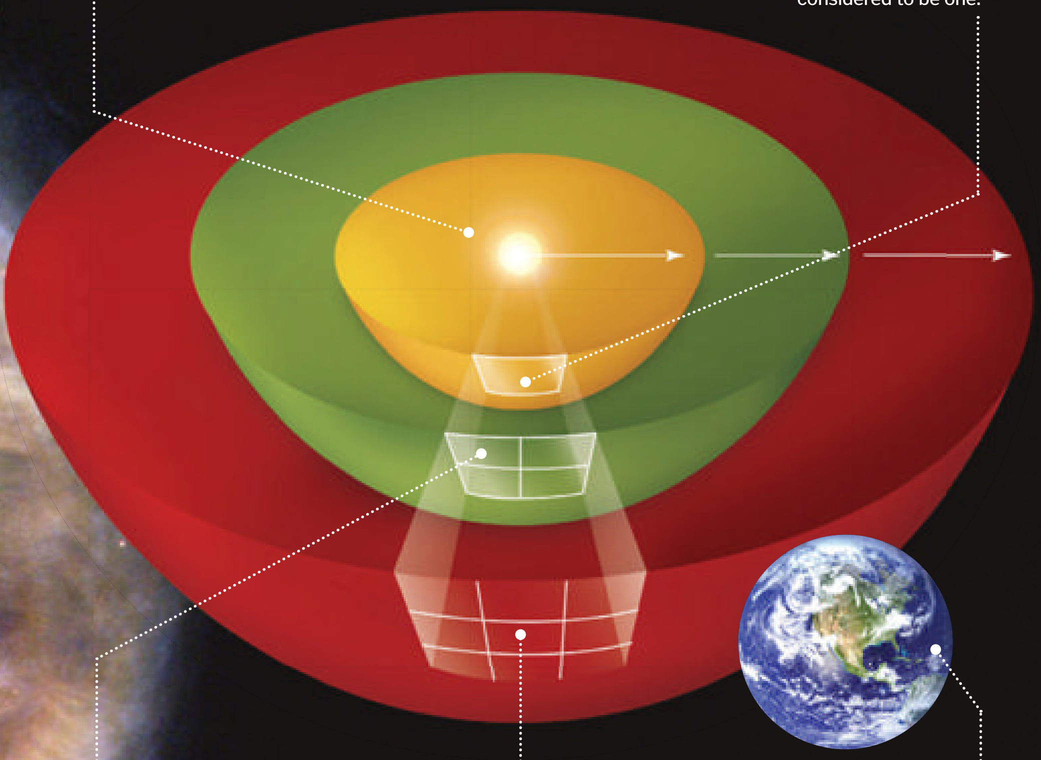
**The Sun**
It won't come as a surprise but there's no brighter object in our sky than the Sun. This G-type star packs an apparent magnitude of -26.7.

**DID YOU KNOW?** *Cepheid variable stars produce the same amount of light energy no matter where they are in the cosmos*



# Luminosity and apparent magnitude explained

**What is the relationship between the light a star emits and what we see on Earth?**



**Cepheid variable**
The farther the light from a Cepheid variable star travels, the more it spreads out.

**One unit**
At one fixed unit of distance from a variable star (usually a parsec), its brightness is considered to be one.

**Two units**
Brightness decreases in an inverse square the farther light travels. At two units away light energy is a quarter of what it was at one.

**Three units**
At three units of distance, light energy is one-ninth what it was at one – then one-16th at four, one-25th at five, and so on.

**Earth**
By the time the light reaches Earth, it's trillions of times less energetic. Here we can measure the star's apparent magnitude.

## Discovering Andromeda

Until the early-20th century it was widely believed our Solar System was part of an 'island universe' – a nebulous mass of stars with nothing beyond its boundaries. What is now known as the Andromeda galaxy 2.6 million light years away was thought to be a 'spiral nebula' on the edge of this island. That was until 1923, when Edwin Hubble (the Hubble telescope's namesake) found a star in Andromeda with a regular cycle of brightening and dimming. It was to become V1: a Cepheid variable, the first named variable star and a reliable distance marker. It helped prove that Andromeda wasn't part of our 'island universe', but was in fact a completely separate entity – another galaxy. From here, astronomers went about looking for other variable stars and discovering hundreds, thousands and, today, millions of other galaxies observable from Earth.

## Why are Cepheids so important?

Distant stars and planetary systems are much too far away for us to take direct measurements, so discovering and observing Cepheid variable stars is vital because astronomers think they can use the periodicity of changes in Cepheid variable brightness to calculate their luminosity. If we know their luminosity then we can also measure their apparent magnitude. Once we have established both a star's apparent magnitude and its luminosity, we can use those measurements to calculate its distance.

The way the information from variable stars is initially used by astronomers is a bit like a detective who is observing a crime scene to build a better idea of what happened. Apparent magnitude, luminosity and distance are all interrelated, so by closely observing the star we can obtain measurements for two of these values, then use them to calculate the third. This not only enables us to gain a better understanding of different types of star, but also helps us to create a much more accurate picture of the cosmos in general.

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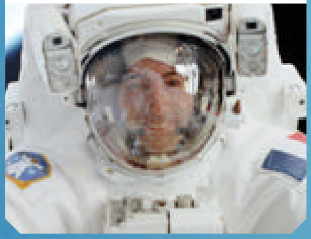
**EXPLORATION**



**SOLAR SYSTEM**

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AMAZING VIDEO! SCAN THE QR CODE FOR A QUICK LINK

See the Moon turn white to red to white again

**DID YOU KNOW?** Ash from volcanoes can fill the Earth's atmosphere with dust and change the shade of a blood Moon

# Blood Moons explained

## Why does our natural satellite sometimes turn bright red?

It's also known as the hunter's Moon and, when the Earth's orbital partner begins to turn that dusky orange colour, it heralds the start of a special kind of lunar eclipse. But why does it turn red?

If, in the middle of the night, you travelled directly along the shadow of the Earth, around 384,000 kilometres (239,000 miles) to the distance the Moon orbits at, then turned around to face our planet, you'd see something amazing: one side of our world plunged into shadow and surrounded by a halo of red light. Effectively, you'd be seeing all the sunsets around the world happening at once from your lofty vantage point – the bright-red tinge caused by short-wavelength sunlight scattering off molecules in the atmosphere and allowing reds, yellows and purples through. During a blood Moon eclipse, as the Moon crosses the threshold of the Earth's shadow from the light of the Sun, it moves into this twilight region, which briefly bathes our natural satellite in the rust-red colour. Over about three hours it moves through to the other side into pure sunlight again, fading back to white. ✱

# Taking photos on the lunar surface

## Learn how Hasselblad cameras were adapted to snap images on Apollo 11

Having established a reputation for robust cameras with quality lenses, Swedish company Hasselblad was selected by NASA to supply most of the photography equipment for the legendary 1969 Apollo 11 mission. But to survive and function in the Moon's atmosphere, they needed to be significantly tweaked.

12 specialised Hasselblad cameras were adapted – all variations of the 500 EL model. The main modifications to those used on the Moon were a bespoke Zeiss lens with precise calibration to ensure high quality and low distortion. They had a glass Reseau plate on the back with a grid on it, used to determine angular distances, plus a silver finish to protect them from the greater temperature variation. They also had a conductive layer to draw away static electricity. Static is generated in any camera where film is wound, but in the near vacuum of the Moon's atmosphere, static has little opportunity to discharge. As a result, it can build up on the non-conductive Reseau plate, creating occasional sparks that pock the film if not diverted. All 12 of Apollo 11's cameras were left on the Moon's surface. ✱

Hasselblad cameras were used on a number of NASA missions, including Apollo 11 and 17, which put the first and last men on the Moon respectively

© NASA; Thinkstock

*"Ariane 4 was the culmination of technology from three generations of Ariane launcher before it"*

# The Ariane 4 launcher

## What made this expendable launcher such a big success?

The last of the Ariane 4 expendable launchers completed its final mission on 15 February 2003. This particular type of launch vehicle design lasted for 15 years and successfully completed 113 launches for a range of government and commercial ventures, capturing 50 per cent of the commercial satellite market at one point during its service career. So what was it about the Ariane 4 that made it so popular across the globe?

Ariane 4 was the culmination of technology from three generations of Ariane launcher before it. It started out as the European Space Agency's (ESA's) attempt to compete with already well-established space organisations like NASA. Europe had tried and failed to develop a space launch vehicle for a decade, so in 1973 the newly formed ESA made a concerted effort to build one, led by France. Ariane 1 first flew in 1979 and, by the time Ariane 4 took to the skies, the launcher was capable of transporting a 2,700-kilogram (5,900-pound) satellite into geostationary orbit.

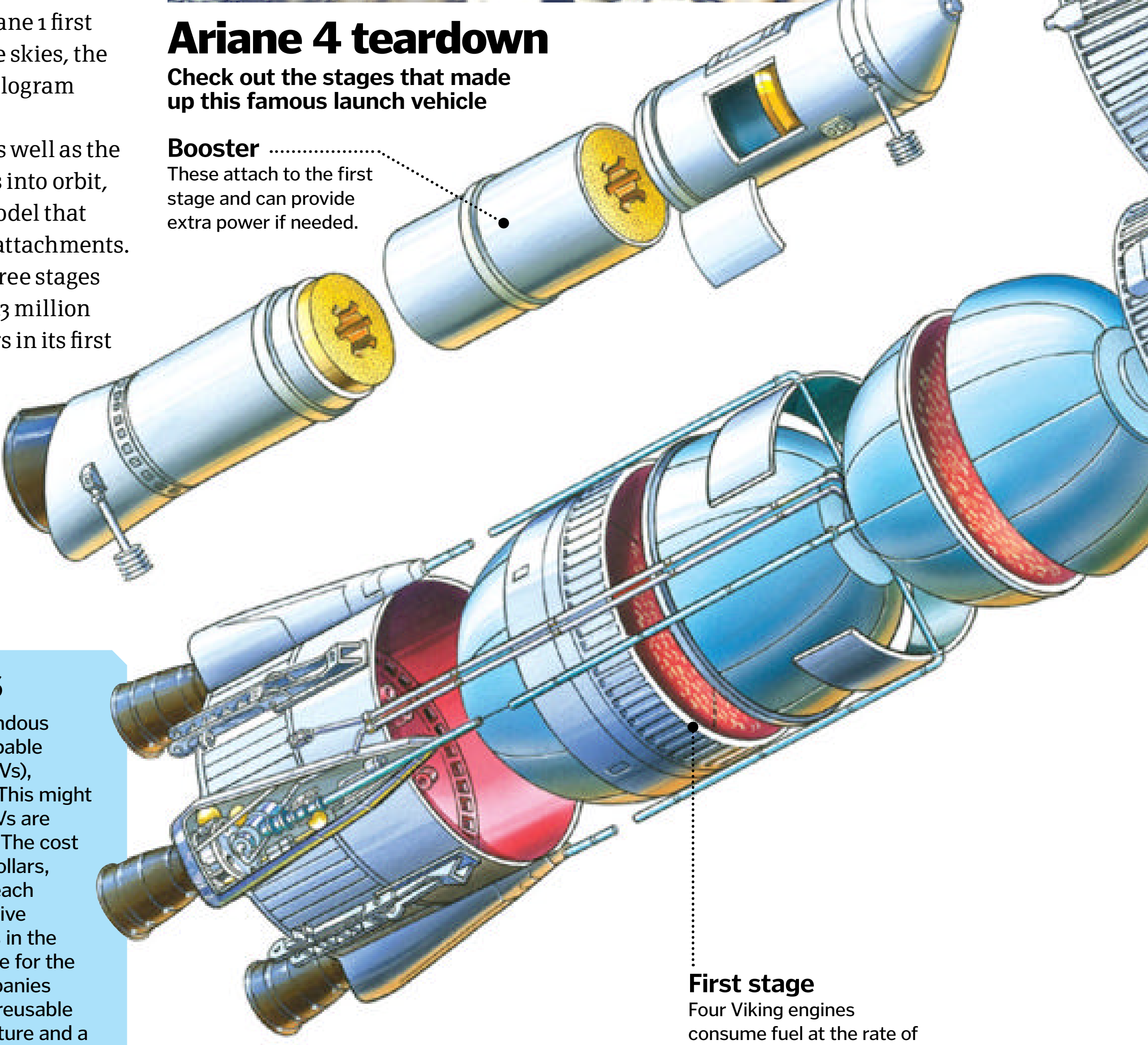
Key to Ariane 4's success was its versatility. As well as the payload system that could launch two satellites into orbit, there were four variants across the standard model that allowed additional solid/liquid rocket booster attachments.

The basic Ariane 4 model – the AR 40 – had three stages with a total thrust of 590,000 kilograms-force (1.3 million pounds-force). There were four Viking 2B motors in its first stage, one Viking 4B motor in its second stage and an HM7B liquid hydrogen (with liquid oxygen oxidiser) motor in the third. The Ariane 4 achieved an exemplary 97 per cent success rate over its career, with only three of its 116 launches ending in failure.

Ariane is one of the ESA's most successful series – particularly Ariane 4 (third from right)

### Ariane 4 teardown

**Check out the stages that made up this famous launch vehicle**



**Booster**
These attach to the first stage and can provide extra power if needed.

**First stage**
Four Viking engines consume fuel at the rate of one ton per second to get Ariane 4 off the ground.

### Enter the expendables

Taking even a small object into orbit costs a tremendous amount in resources and requires a particularly capable machine, known as expendable launch vehicles (ELVs), so-called because they aren't recovered for reuse. This might seem wasteful, but there are good reasons why ELVs are sometimes preferable to reusable launch systems. The cost of a shuttle orbiter can run into tens of billions of dollars, plus recovery and maintenance costs it incurs for each successive launch. The most advanced and expensive version of the Ariane 4 (the 44L), meanwhile, costs in the region of £60 million ($100 million) – pocket change for the likes of NASA and major telecommunications companies interested in sending unmanned craft into orbit. A reusable shuttle also requires a much more protective structure and a recovery system, which reduce its payload capacity.

## HEAD 2 HEAD
LAUNCHER SHOWDOWN

**1. BUSIEST**

**Soyuz**

This Russian launcher has an impressive 745 launches under its belt since it started operating in 1973 – 724 of which have been successful.

**2. LIGHTEST**

**Delta II**

At 231,870 kilograms (511,180 pounds), the US Delta II's fully loaded mass is the lightest. The Ariane 44L, by contrast, can take off weighing 470 tons.

**3. TALLEST**

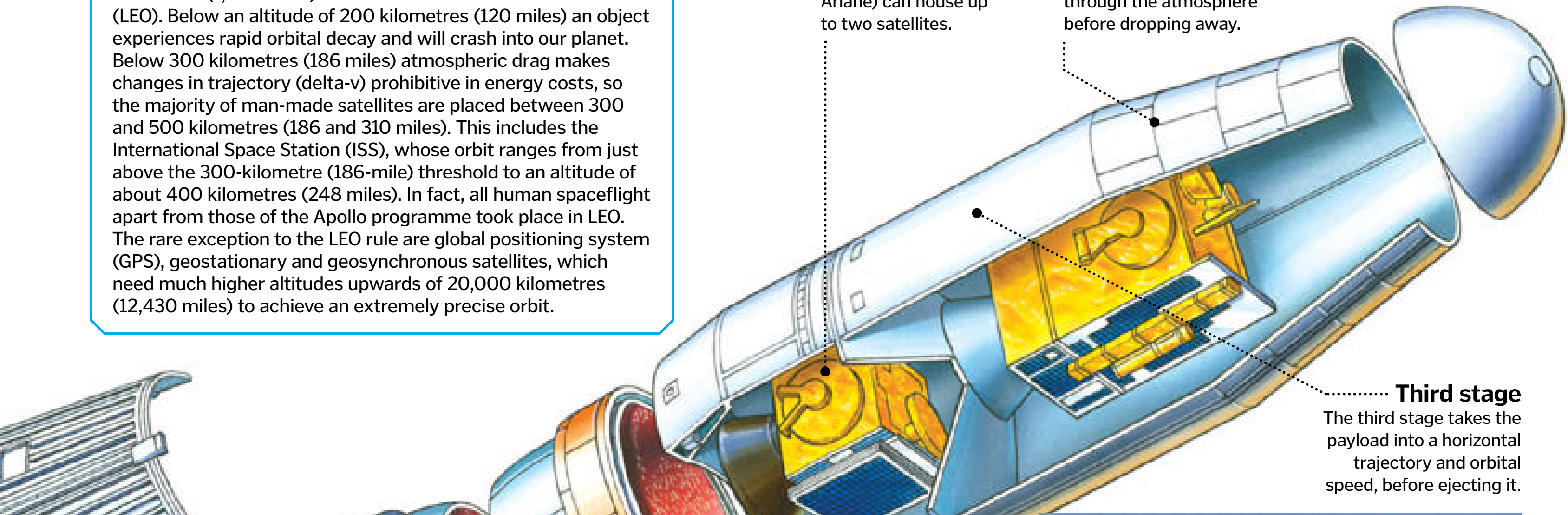
**Ariane 4**

With a height of 58.7 metres (192.7 feet), Ariane 4 is the tallest launch system there has been to date by around ten metres (33 feet).

**DID YOU KNOW?** *Ariane (from Ariadne) is named after the mythological princess who helped Theseus escape the Labyrinth*

## Getting to LEO

Any object that orbits the Earth below an altitude of 2,000 kilometres (1,240 miles) is considered to be in low-Earth orbit (LEO). Below an altitude of 200 kilometres (120 miles) an object experiences rapid orbital decay and will crash into our planet. Below 300 kilometres (186 miles) atmospheric drag makes changes in trajectory (delta-v) prohibitive in energy costs, so the majority of man-made satellites are placed between 300 and 500 kilometres (186 and 310 miles). This includes the International Space Station (ISS), whose orbit ranges from just above the 300-kilometre (186-mile) threshold to an altitude of about 400 kilometres (248 miles). In fact, all human spaceflight apart from those of the Apollo programme took place in LEO. The rare exception to the LEO rule are global positioning system (GPS), geostationary and geosynchronous satellites, which need much higher altitudes upwards of 20,000 kilometres (12,430 miles) to achieve an extremely precise orbit.



**SPELDA**

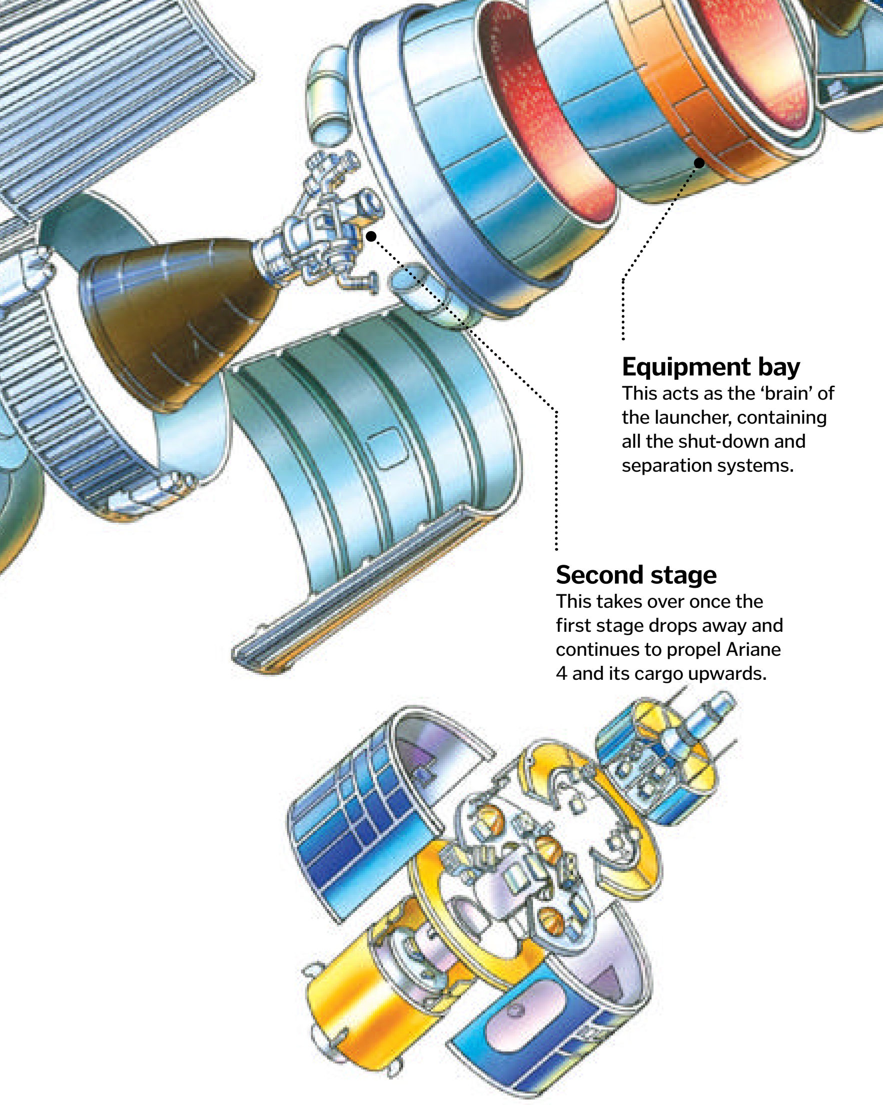
The SPELDA (Structure Porteuse Externe pour Lancements Doubles Ariane) can house up to two satellites.

**Fairing**

The payload is shielded by a fairing that protects the satellite(s) while passing through the atmosphere before dropping away.

**Third stage**

The third stage takes the payload into a horizontal trajectory and orbital speed, before ejecting it.



**Equipment bay**

This acts as the 'brain' of the launcher, containing all the shut-down and separation systems.

**Second stage**

This takes over once the first stage drops away and continues to propel Ariane 4 and its cargo upwards.

Ariane 4's service career lasted from June 1988 through to February 2003

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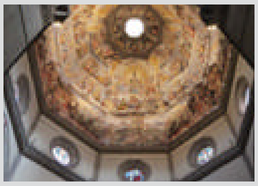
## The statistics...



**Florence Cathedral**

**Height:** 114.5m (375ft)

**Length:** 153m (502ft)

**Width:** 38m (125ft)

**Cost:** At least £500m ($802m)

**Date of construction:**
1296-1436

**Architect:**
At least 11 different architects

# Florence Cathedral

## Crowned with the largest masonry dome in the world, Florence Duomo is a Renaissance masterpiece

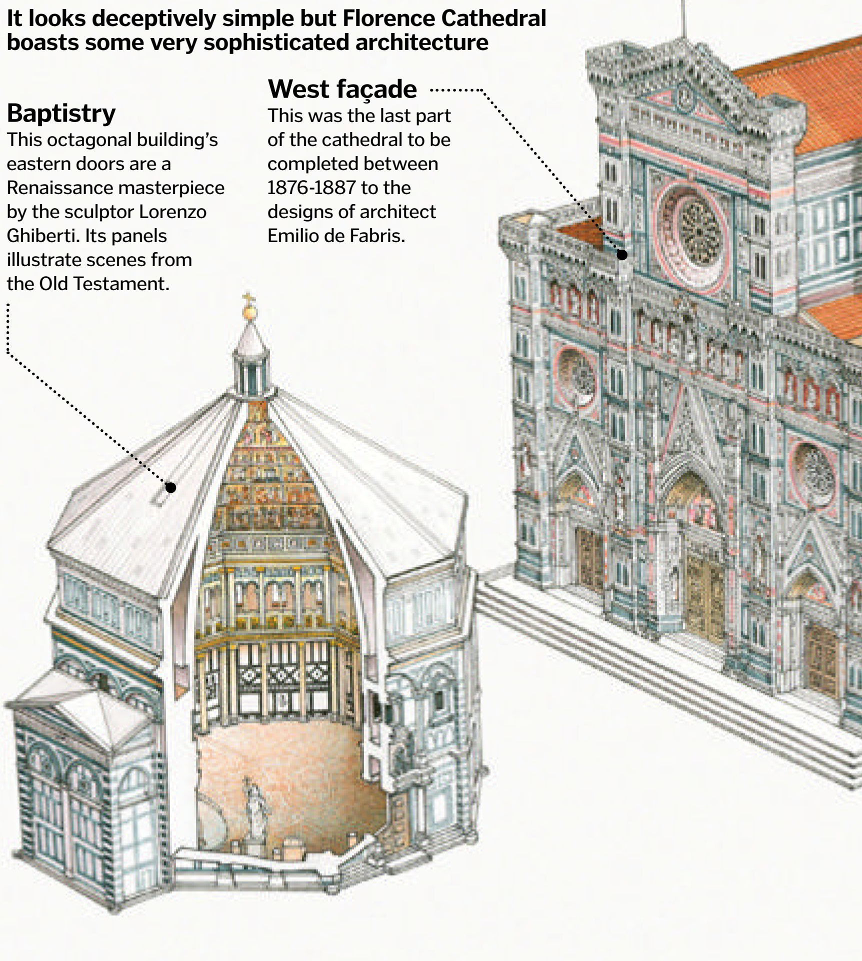
Popularly called the Duomo, Florence Cathedral's name is derived from the Latin 'domus dei' – the House of God – and is dedicated to the Virgin Mary Santa Maria del Fiore (St Mary of the Flower). The present building was started in 1296 and is the third cathedral to stand on the site. Taking 140 years to build, the original plan was only changed once during construction when the eastern half of the cathedral was massively expanded to allow for the now iconic dome. Work on this extraordinary structure began in 1420 and was completed in just 16 years. Higher and wider than any previously built, the octagonal dome was constructed without using a temporary wooden supporting frame. Consisting of a double shell made of sandstone, marble and brick, the base of the dome is 52 metres (171 feet) above the ground and has a staggering 44-metre (144-foot) diameter.

The cathedral's exterior walls are faced in alternate vertical and horizontal bands of coloured marble – white from Carrara, green from Prato and red from Siena. Despite the many architects to work on it the building retains a remarkable architectural and aesthetic cohesion. The interior is sparsely decorated, but contains a number of major Renaissance artworks and 44 stained-glass windows – in fact, the largest expanse of glass installed during 14th and 15th-century Italy.

Above the main door is the basilica's one-handed liturgical clock, which shows all 24 hours. Erected in 1443, it is still working today. The largest cathedral in Europe when it was built, it has become symbolic of Florence and its dome is instantly recognised around the globe. Such is the Duomo's cultural importance that the cathedral complex was designated a UNESCO World Heritage site in 1982.

## A tour of the basilica

**It looks deceptively simple but Florence Cathedral boasts some very sophisticated architecture**



### Baptistry

This octagonal building's eastern doors are a Renaissance masterpiece by the sculptor Lorenzo Ghiberti. Its panels illustrate scenes from the Old Testament.

### West façade

This was the last part of the cathedral to be completed between 1876-1887 to the designs of architect Emilio de Fabris.

# KEY DATES
## THE DUOMO

**1296**
The building of the present cathedral begins to the east of the old cathedral of St Reparata.

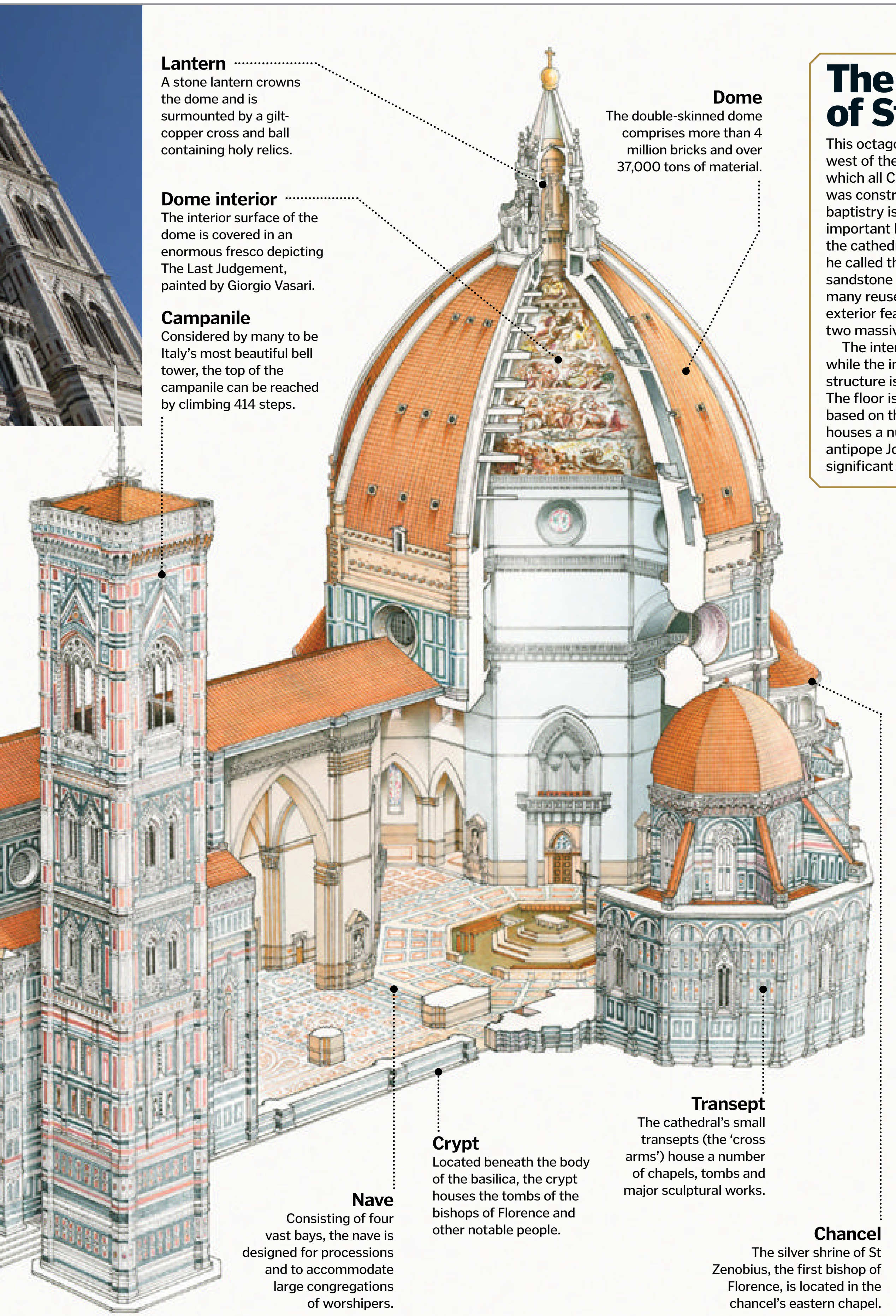
**1436**
The cathedral is formally consecrated by Pope Eugene IV (right).

**1439**
The Council of Florence is held to try and reunify the Orthodox and Catholic churches.

**1865**
Florence is made capital of the newly created Kingdom of Italy; the Duomo is its cathedral.

**1887**
The cathedral's neogothic west façade is finally completed.

**DID YOU KNOW?** *The famous English mercenary, Sir John Hawkwood, was buried in Florence Cathedral in 1394*



**Lantern**
A stone lantern crowns the dome and is surmounted by a gilt-copper cross and ball containing holy relics.

**Dome**
The double-skinned dome comprises more than 4 million bricks and over 37,000 tons of material.

**Dome interior**
The interior surface of the dome is covered in an enormous fresco depicting The Last Judgement, painted by Giorgio Vasari.

**Campanile**
Considered by many to be Italy's most beautiful bell tower, the top of the campanile can be reached by climbing 414 steps.

**Nave**
Consisting of four vast bays, the nave is designed for processions and to accommodate large congregations of worshipers.

**Crypt**
Located beneath the body of the basilica, the crypt houses the tombs of the bishops of Florence and other notable people.

**Transept**
The cathedral's small transepts (the 'cross arms') house a number of chapels, tombs and major sculptural works.

**Chancel**
The silver shrine of St Zenobius, the first bishop of Florence, is located in the chancel's eastern chapel.

## The Baptistry of St John

This octagonal building stands slightly to the west of the cathedral. Built to house the font in which all Christians in Florence were baptised, it was constructed between 1059 and 1128. The baptistry is famous for three sets of artistically important bronze doors. The eastern pair, facing the cathedral, so impressed Michelangelo that he called them the 'Gates of Paradise'. Made of sandstone and faced with marble incorporating many reused fragments of Roman buildings, the exterior features many sculptural groups and two massive porphyry columns.

The interior of the baptistry is clad in marble, while the inside of the dome which roofs the structure is inlaid with magnificent gold mosaics. The floor is covered in marble featuring a design based on the zodiac. Unusually, the baptistry also houses a number of tombs, including that of the antipope John XXIII which is considered a significant early-Renaissance sculptural work.

## Giotto's campanile

The campanile, or bell tower, was designed by the celebrated painter Giotto di Bondone and it houses seven bells. Standing next to the cathedral, it is built from the same coloured marbles and so blends in well with its neighbour. The tower is square in plan with sides measuring 15 metres (47 feet) and it soars 87 metres (278 feet) high. Embraced by polygonal buttresses at its corners, it's divided into five separate levels – the upper three of which contain windows. Each of the three top levels is larger than the one below it in every dimension. These differences in size counter the effect of perspective so when viewed from below, the three top levels of the tower look equal in size. Although Giotto originally intended the campanile to be surmounted by a tall spire, after his death it was decided to build a large projecting terrace instead, which lends the tower a dramatic 'broken off' look.

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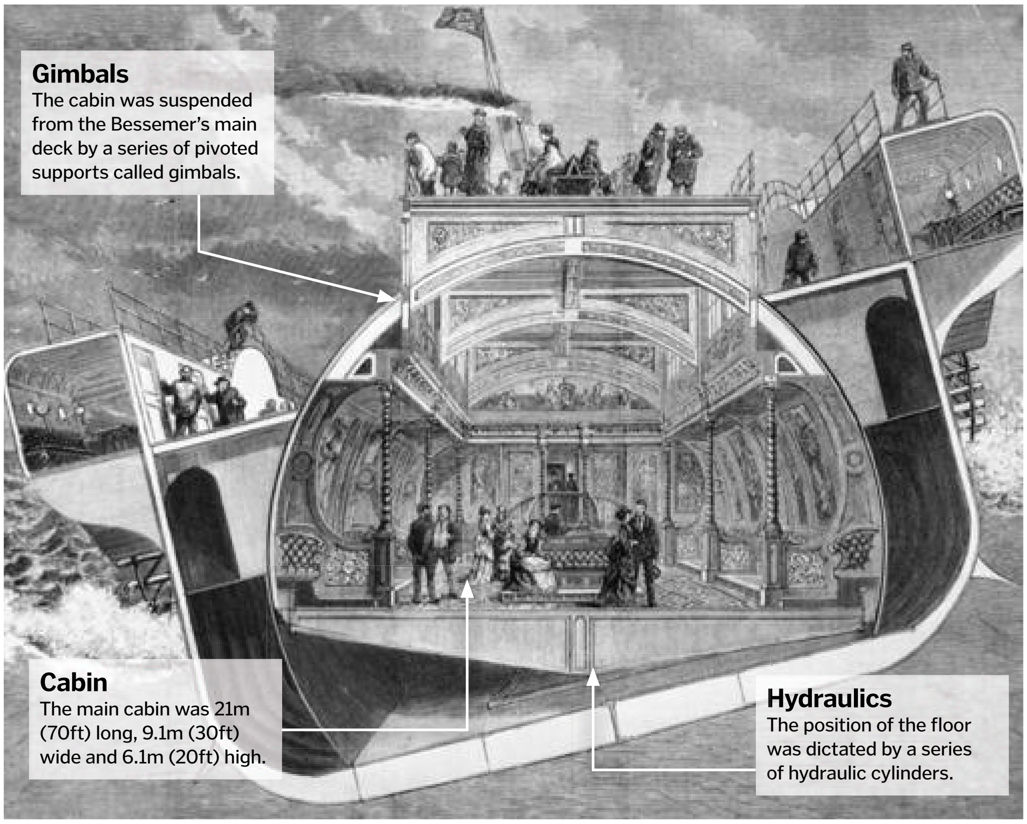
> "While the suspension system worked, the shifting centre of gravity made the ship almost unsteerable"

# Why swinging saloons failed

## The SS Bessemer was a revolutionary new design of vessel that infamously didn't work – find out why it failed



**Gimbals**
The cabin was suspended from the Bessemer's main deck by a series of pivoted supports called gimbals.

**Cabin**
The main cabin was 21m (70ft) long, 9.1m (30ft) wide and 6.1m (20ft) high.

**Hydraulics**
The position of the floor was dictated by a series of hydraulic cylinders.

The SS Bessemer was an experimental Victorian ship that attempted to solve the age-old problem of seasickness among passengers by isolating the main cabin (saloon) from the rest of the vessel. The idea behind this was that if the main saloon could remain stationary (horizontal) in relation to the tilting hull of the ship, then passengers would not be exposed to stomach-churning, unnatural movements while on board.

The cabin was isolated by suspending it on gimbals from the deck and kept horizontal mechanically by an array of hydraulic cylinders controlled by a steersman. To keep the cabin floor at 180 degrees, the steersman simply consulted a spirit level to determine the tilt and then counteracted it. On paper it seemed like an ingenious solution; in reality, however, it was to prove a monumental failure.

While the suspension system worked, mitigating a large amount of cabin sway, the shifting centre of gravity made the ship almost unsteerable and very unpredictable while at sea – two factors that led it to crash into Calais pier on its first trip. The poor performance at sea, catastrophic maiden voyage and huge costs involved in the project saw it being wound up, with the ship dismantled only four years after its first – and last – commercial voyage.

# Horse armour explained

## If you thought it was only the knights who were protected from head to toe during battle, it's time to think again…

Medieval combat largely revolved around mounted engagements, with cavalry playing a crucial role in the majority of battles. Keeping horses alive and in good condition was therefore imperative to success, with arrows, spears and swords often targeting the animal over the rider due to the knight's extensive armour.

As such, armour for horses (known as barding) became increasingly prevalent through the 14th and 15th centuries and grew in both stature and complexity until horses were equipped with a variety of battle gear.

Armour plates included: a champron – a type of helmet worn to protect the horse's head; a crinière, which was a series of armour plates that encircled the animal's neck; and a breastplate called a peytral. It would also have a pair of flanchards, which were two armoured panels that sat either side of the knight's saddle as well as a croupiere – a large plate or chain dome that shielded the horse's hindquarters.

Combined, these pieces of armour left very little of the horse's body exposed, allowing it to charge through volleys of arrows without being compromised. It was only vulnerable to well-placed spear or sword incisions, which were incredibly difficult to achieve if you were being charged down at speed!

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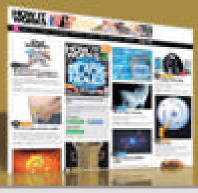

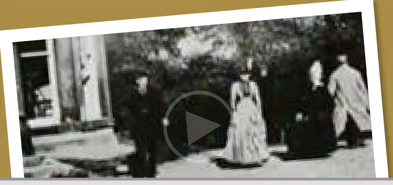

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**DID YOU KNOW?** *The oldest film shot with a cinecamera – the Roundhay Garden Scene – dates from 1888*

# Inside cinecameras

## How were the original motion pictures captured on film?

Cinecameras were – and to a certain extent still are – a machine for recording motion pictures on celluloid film stock – a widely used analogue form of image storage. Cinecameras work by feeding film stock – a transparent polyester strip that's coated with light-sensitive emulsion – from a forward magazine (a light-free chamber) through a transportation system, across an image exposure point and then back into another magazine at the rear.

The total recording process works as follows. Firstly, film stock from the forward magazine is mechanically driven via sprocket-powered gears into an enclosed exposure chamber (film gate). This is executed by a mechanical claw, which pulls the film into position behind the shutter, fixing it temporarily in place.

At this point the camera's shutter opens and exposes the image that the lens is currently capturing onto the locked segment of film. The claw then draws the exposed film segment down and out of the exposure chamber, advancing the stock, ready for the next exposure. At the same time as the claw draws the film down, the camera's shutter closes in sync and is then primed to open once more for the following exposure; if the shutter was left open continuously, the images would be ruined through overexposure.

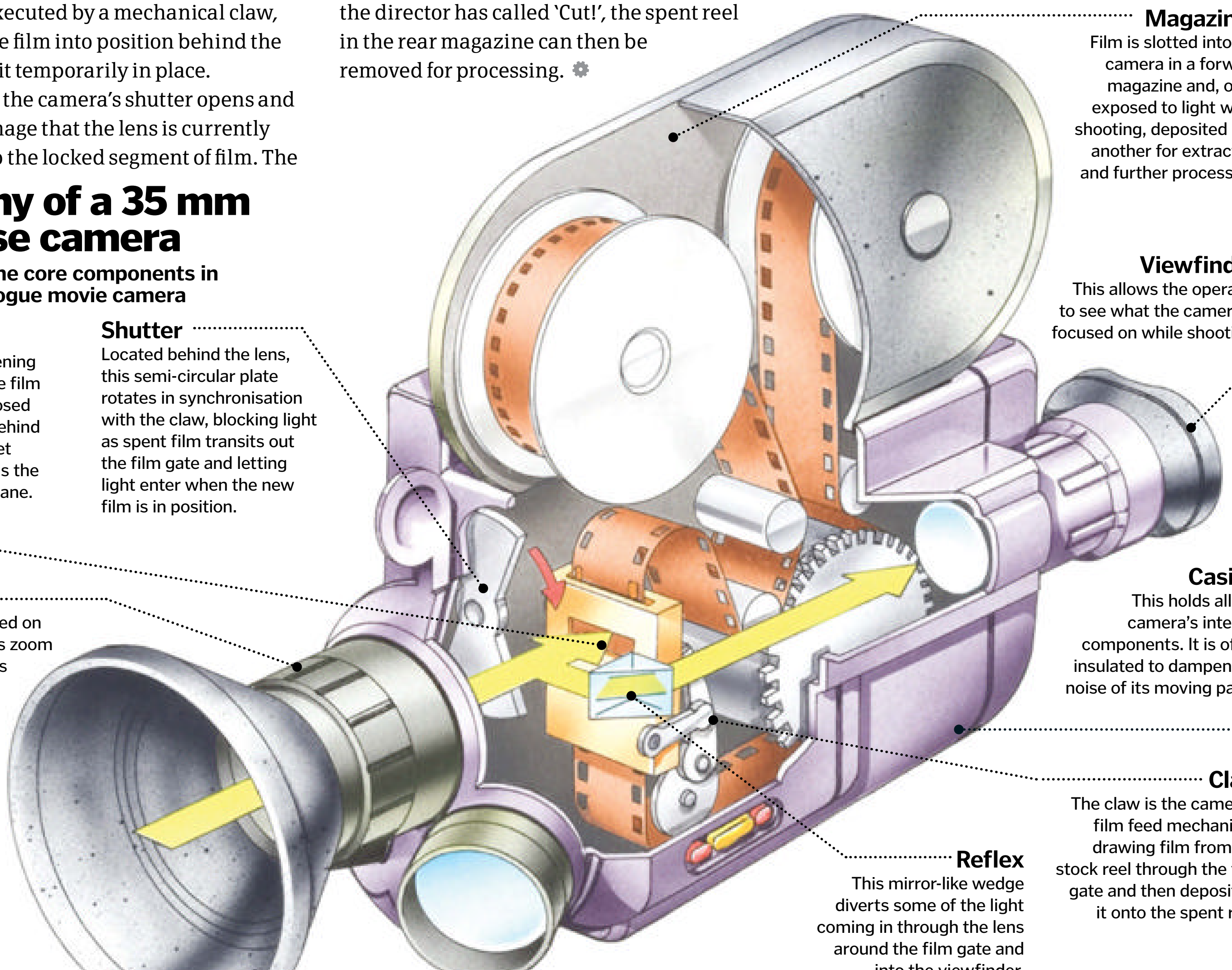
This process continues throughout shooting, with a succession of images being exposed onto the film stock in sequence. After each image – more commonly referred to as a 'frame' – leaves the exposure chamber, it is drawn into a rear magazine for storage in reel format. Once the director has called 'Cut!', the spent reel in the rear magazine can then be removed for processing.

### The rise of digital

There are a few key reasons for the shift from film-based to digital recording. Firstly, film is very expensive compared with the electronic storage used to record films digitally, allowing low-budget productions to operate on a fraction of the cost. Secondly, due to the mechanical components of film-based cameras, portability can also be an issue, with certain components requiring a specific form factor; this is not the case with digital cameras. Thirdly, many modern digital cameras are capable of recording footage at a far higher resolution than traditional film cameras, such as the RED Scarlet 5K. Lastly – and one of the most important factors – recording digitally allows for a much higher degree of modification in postproduction.

## Anatomy of a 35 mm cellulose camera

**Learn about the core components in a typical analogue movie camera**



**Film gate**
A rectangular opening through which the film passes to be exposed to light. It is set behind the shutter at a set distance and holds the film on an even plane.

**Shutter**
Located behind the lens, this semi-circular plate rotates in synchronisation with the claw, blocking light as spent film transits out the film gate and letting light enter when the new film is in position.

**Zoom lens**
Scenes are focused on with the camera's zoom lens, which allows the operator a great degree of freedom in shot composition.

**Magazines**
Film is slotted into the camera in a forward magazine and, once exposed to light while shooting, deposited into another for extraction and further processing.

**Viewfinder**
This allows the operator to see what the camera is focused on while shooting.

**Casing**
This holds all the camera's internal components. It is often insulated to dampen the noise of its moving parts.

**Claw**
The claw is the camera's film feed mechanism, drawing film from the stock reel through the film gate and then depositing it onto the spent reel.

**Reflex**
This mirror-like wedge diverts some of the light coming in through the lens around the film gate and into the viewfinder.

© Thinkstock

> "The battle was the culmination of years of tension between the Native American tribes and US government"

# The Battle of Little Bighorn

## One of the most infamous conflicts in American history, Little Bighorn is proof that winning the battle doesn't always result in winning the war

The Battle of Little Bighorn was a fierce clash that occurred over 25-26 June 1876, between the US military's 7th Cavalry division and the combined might of multiple Lakota Sioux, Cheyenne and Arapaho Native American tribes. Lieutenant Colonel George Armstrong Custer commanded the 7th Cavalry division, while the Native American force was led by Sitting Bull.

Ending with a crushing defeat for the military's forces – including the death of Custer and five of the 7th Cavalry's companies – it was a key turning point of the American Indian Wars. While the Native Americans emerged victorious from the battle, the scale of white American losses led to federal forces overrunning the region in retaliation.

The battle was the culmination of years of heightening tension between the Native American tribes and US government, with more and more of the Native American lands consumed each year by westward territorial expansion of white settlers. These tensions boiled over when, following the signing of the Second Treaty of Fort Laramie – which promised the Indians certain territories – sacred areas like the Black Hills were invaded by prospectors hunting for gold.

This, in partnership with the US government's indecisive policy toward the Native Americans, led to federal troops being deployed in the region to relocate any Indians not yet in reservations. This action was what sparked the Battle of Little Bighorn.

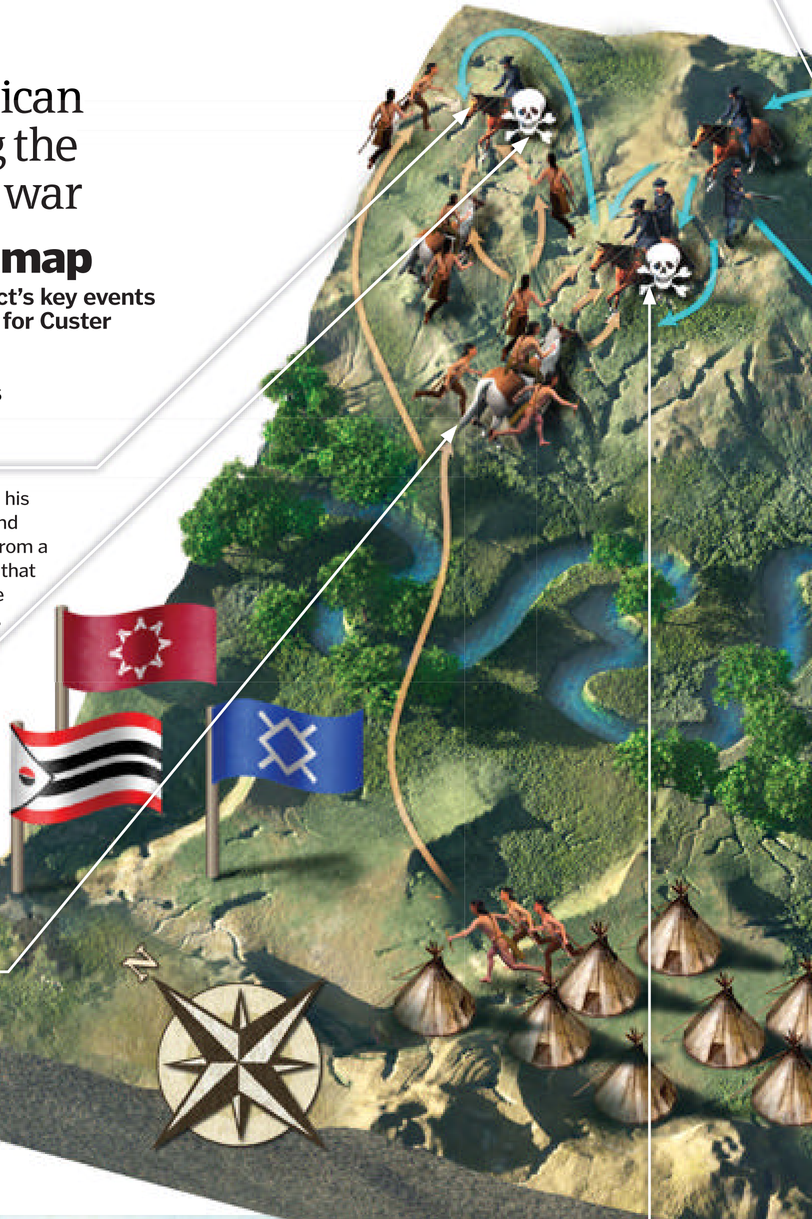
Following the battle the remaining Native American tribes fled from their lands in the wake of the US military's retaliation. Gradually remaining Indians either were killed in other smaller skirmishes, escaped across the border into Canada or surrendered to the United States – the latter leading to the establishment of the permanent Native American reservations which still exist to this day.

## Bighorn battle map

**HIW runs through the conflict's key events and where it all went wrong for Custer**

**Key**

- ▨ **Native American Warriors**
- ▨ **US Cavalry**



**6. Keogh falls**
Captain Myles Keogh splits off from Custer's force to meet the approaching Native American force led by Chief Gall. He is heavily outnumbered though and dies along with all of his company defending Custer's position.

**7. Crazy Horse attacks**
Crazy Horse attacks Custer's force head on, with Custer and First Lieutenant James Calhoun digging in to try and protect their position.

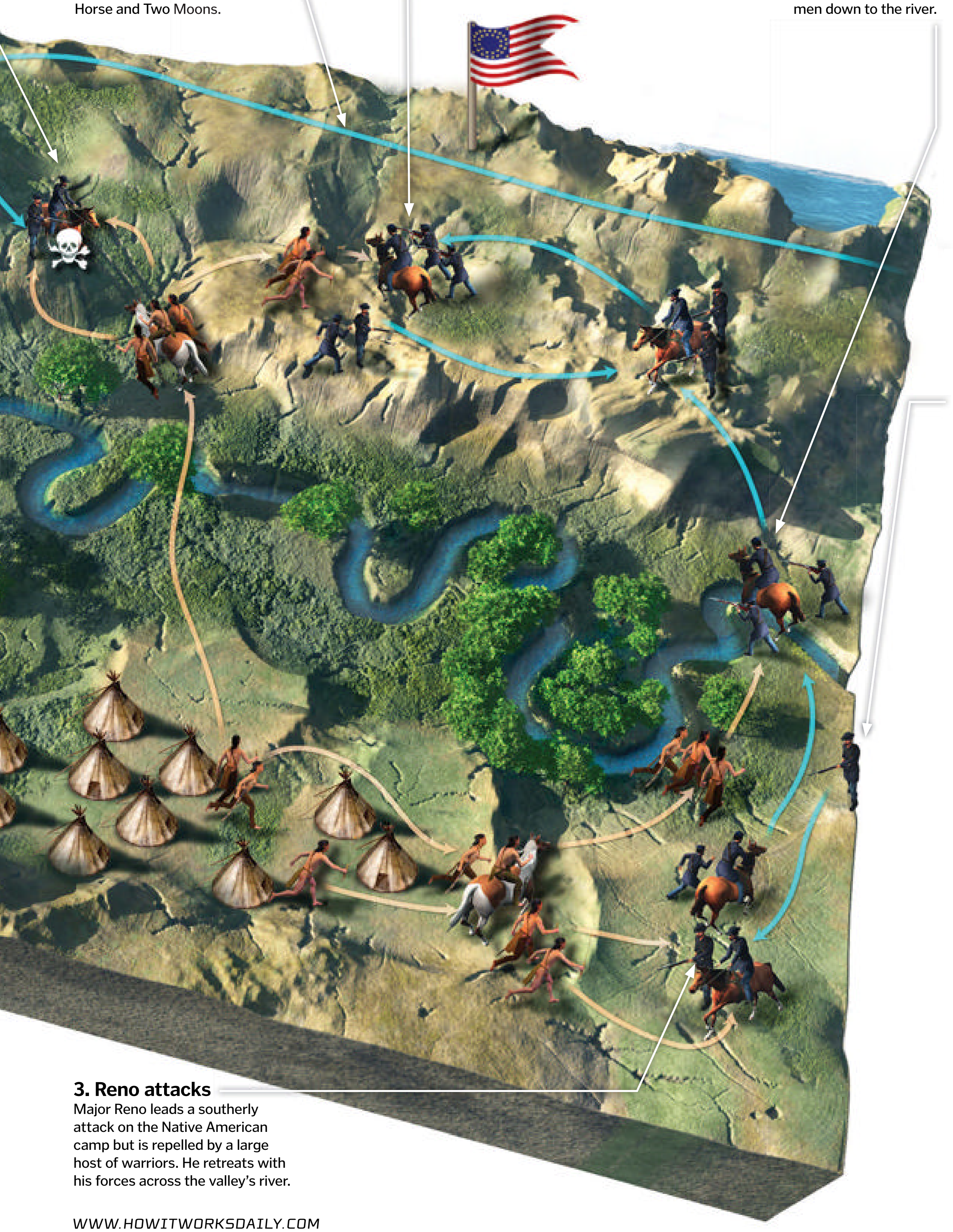
**8. Custer splits**
Custer breaks off from Calhoun and his men in an attempt to gain ground and attack the Native American forces from a different angle. Little does he know that a group of Indians have already rode around to the north to outflank him.

**9. Calhoun dies**
Without Custer's men the fierce fighting between the US soldiers and the Native American forces led by Crazy Horse and Two Moons swings in the latter's favour, leading to Calhoun to be cut down along with most of his troops.

**10. The last stand**
Isolated from the remaining forces of Reno and Benteen, Custer is surrounded by enemy forces and is killed with his entire group of soldiers on what is now known as Last Stand Hill.

During the Battle of Little Bighorn the Native American warriors both outnumbered and outmanoeuvred the federal soldiers

**DID YOU KNOW?** George Armstrong Custer graduated bottom of his class at West Point Military Academy



### 2. Encircle

Custer leads the third group of cavalry north in an attempt to encircle the Native American settlement and attack it from three sides. He is met, however, by a large force led by Chiefs Crazy Horse and Two Moons.

### 5. Weir breaks rank

Captain Thomas Weir breaks rank from Benteen's troops in an attempt to make contact with Custer. They are met by Native Americans that have splintered off from a force led by Chief Gall.

### 4. Benteen arrives

Captain Benteen arrives in position late and is joined by the retreating Reno. The forces combine in order to fend off a Native American counterattack, which has pursued Reno's men down to the river.

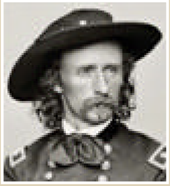
### 1. Split

Lieutenant Colonel Custer splits his force into three, with two sets of troops – led by Major Marcus Reno and Captain Frederick Benteen – attacking the Native American settlement either side of the river.

### 3. Reno attacks

Major Reno leads a southerly attack on the Native American camp but is repelled by a large host of warriors. He retreats with his forces across the valley's river.

## Custer: hero or villain?



Following his death, Custer received much public fame, being honoured as a military hero and fearless fighter. This view was entrenched by books written by his wife, the coining of the phrase 'Custer's last stand' and the production of many romanticised depictions in art. However, Custer and his actions also received much criticism. Speaking to the *New York Herald* in 1876, President Ulysses S Grant said that he regarded "Custer's massacre as a sacrifice of troops, brought on by Custer himself, that was wholly unnecessary." Further, modern historians indicate Custer was very reckless in his pursuit of the Native American tribes.

## Who was Sitting Bull?

Sitting Bull – aka Tatanka Iyotake – was a Teton Dakota chief who united the myriad Sioux tribes during the 1870s in an attempt to survive the influx of white Americans over the Great Plains. Iyotake was born in modern-day South Dakota in 1831 and, through a series of impressive performances in wars, ascended through the ranks to become principal chief of the Sioux nation in 1867. In 1868 Sitting Bull persuaded the Sioux to agree with the Second Treaty of Fort Laramie, which guaranteed the Sioux a large area of land in South Dakota. However, after gold deposits were found in the area, prospectors invaded the protected lands leading to a series of events that would eventually culminate in the Battle of Little Bighorn.

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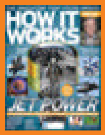
# BRAIN DUMP

Because enquiring minds want to know...



## Ask your questions

Send us your queries using one of the methods opposite and we'll get them answered

## MEET THE EXPERTS

Who's answering your questions this month?

**Luis Villazon**

Luis has a degree in Zoology from Oxford University and another in Real-time Computing. He's been writing about science and tech since before the web. His science-fiction novel *A Jar Of Wasps* is published by Anarchy Books.

**Giles Sparrow**

Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in publishing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries*.

**Alexandra Cheung**

With degrees from the University of Nottingham and Imperial College, Alex has worked for several scientific organisations including London's Science Museum, CERN and the Institute of Physics. She lives in Ho Chi Minh City, Vietnam.

**Tom Harris**

Hailing from North Carolina, Tom is an experienced science writer who, over the years, has produced hundreds of articles which demystify complex subjects for both magazines and general knowledge books. In his spare time he's a keen dog rescue volunteer.

**Dave Roos**

A freelance writer based in the USA, Dave has researched and written about every conceivable topic, from the history of baseball to the expansion of the universe. Among his many qualities are an insatiable curiosity and a passion for science.

# Why does welding cause sparks?

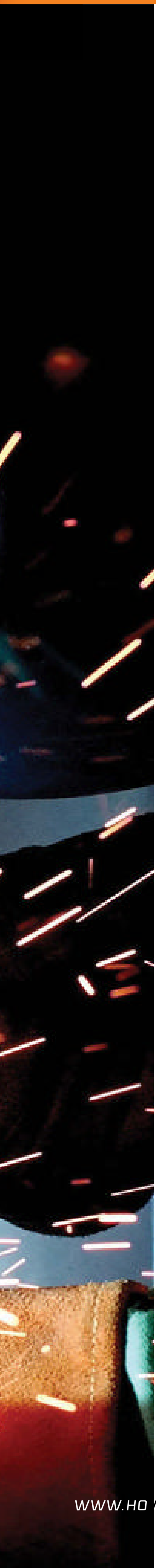
**Eric Kamprad**

■ Welding involves heating two pieces of metal (or plastic) so that they melt and fuse together, resulting in a very strong seam. This requires scorching temperatures of around 5,500 degrees Celsius (9,900 degrees Fahrenheit), which are most commonly generated with an electric arc.

An arc is a discharge of electrical current – just like a tiny lightning bolt. In arc welding, the parts to be welded are connected to a grounded wire, and an electrode (made of filler metal) is connected to the power supply. When the electrode is put into contact with the welding materials, then moved away, the air in between the two is ionised and electrons leap across the gap. This generates bright light and intense heat. As the arc is drawn along the join, both the tip of the electrode and the working materials become liquid and fuse together. At such high temperatures, the molten metal bubbles and spits, expelling a shower of incandescent droplets: these are the sparks you see. They can be as hot as 1,300 degrees Celsius (2,500 degrees Fahrenheit) so be sure to stand clear!

**Alexandra Cheung**

Welding uses the process of coalescence to fuse materials together at an atomic level

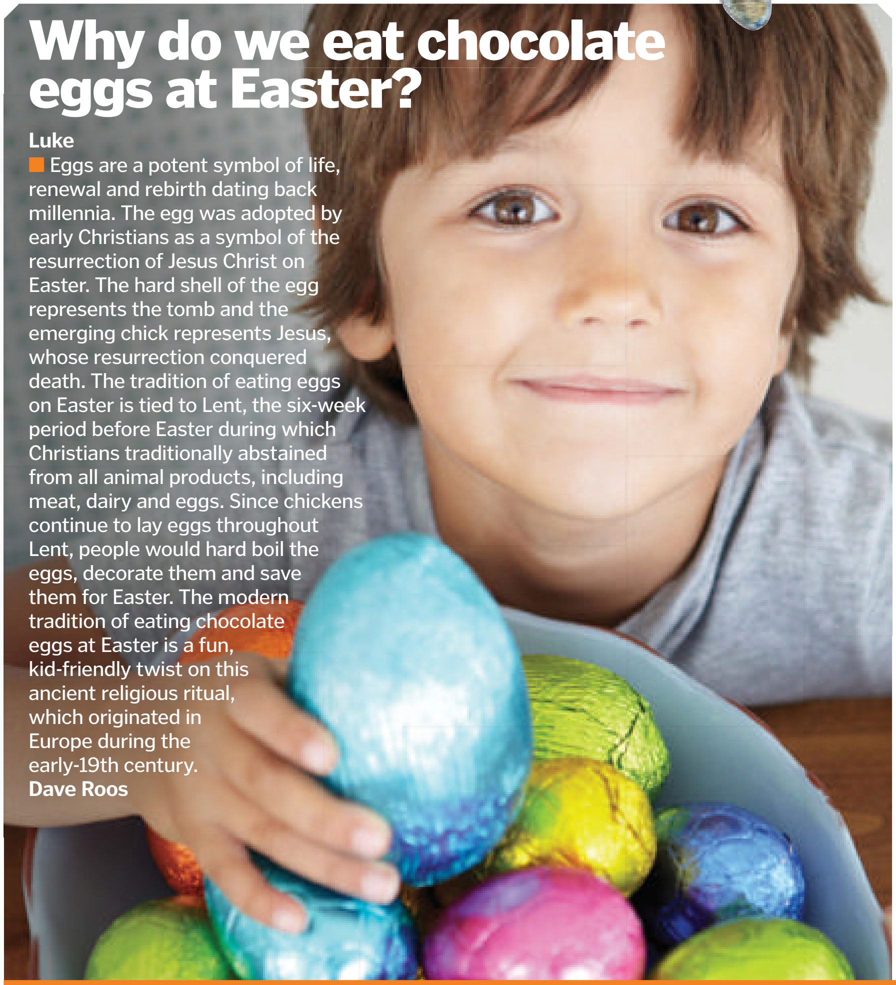


# Who were the Templars?

**Donald Cousins**

The order of the Knights Templar was a small contingent of warrior monks who defended Christian pilgrimage sites in the Holy Land in the Middle Ages. Christian Crusaders took Jerusalem in 1099, but struggled to maintain control of venerated holy sites tied to the birth, life and crucifixion of Jesus. In 1119, two French knights swore to defend these sites from 'infidels' and protect Christian pilgrims. They amassed a small band of compatriots and were given shelter in the Al-Aqsa Mosque, which is believed to be the ancient site of King Solomon's Temple. In 1129, the Knights Templar military order took monastic vows of chastity and poverty. Soon they received recognition and financial support from the Vatican, and were given land by kings and feudal lords throughout Europe. Christians were expelled from the Holy Land in 1291, and the Knights Templar never recovered. The Templars' grand master, Jacques de Molay, was arrested in 1307 by the king of France and accused of heresy, sodomy and idol worship. Although the charges and Molay's 'confession' were almost certainly false, the leader of the Templars was burned at the stake.

**Dave Roos**

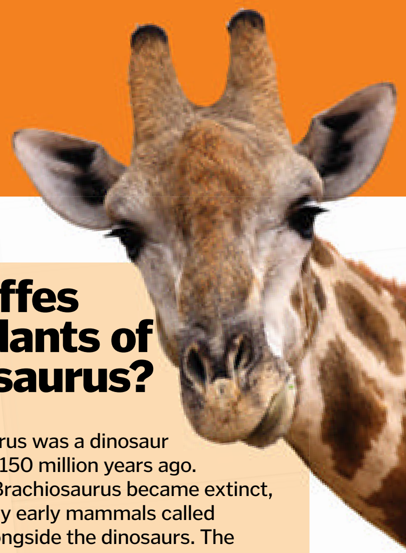


# Why do we eat chocolate eggs at Easter?

**Luke**

Eggs are a potent symbol of life, renewal and rebirth dating back millennia. The egg was adopted by early Christians as a symbol of the resurrection of Jesus Christ on Easter. The hard shell of the egg represents the tomb and the emerging chick represents Jesus, whose resurrection conquered death. The tradition of eating eggs on Easter is tied to Lent, the six-week period before Easter during which Christians traditionally abstained from all animal products, including meat, dairy and eggs. Since chickens continue to lay eggs throughout Lent, people would hard boil the eggs, decorate them and save them for Easter. The modern tradition of eating chocolate eggs at Easter is a fun, kid-friendly twist on this ancient religious ritual, which originated in Europe during the early-19th century.

**Dave Roos**



# Are giraffes descendants of Brachiosaurus?

**Tom**

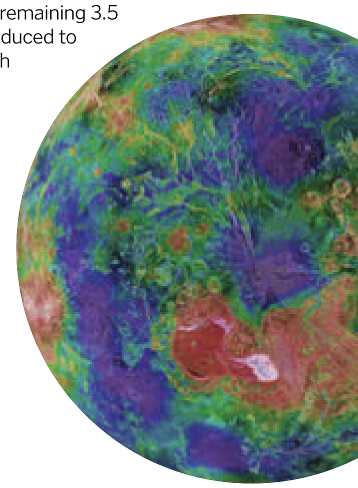
No. Brachiosaurus was a dinosaur that lived around 150 million years ago. By the time that Brachiosaurus became extinct, there were already early mammals called Eutheria living alongside the dinosaurs. The Eutheria gave rise to the placental mammals and then the Artiodactyla and, eventually, the modern giraffe. The most recent common ancestor of the Brachiosaurus and the giraffe would have been an amniote vertebrate – somewhere between a reptile and an amphibian – that lived about 340 million years ago. Confusion might arise from the name of one of these great sauropods: Brachiosaurus giraffatitan. This means 'giant giraffe', but the physical resemblance between the two animals is actually quite superficial. They are both large quadrupeds, but the long neck of the Brachiosaurus comprised dozens of separate vertebrae whereas the giraffe has just seven. This is the same number as you have in your neck; it's just that the giraffe vertebrae are each a lot longer. It takes less time to evolve longer bones than it does to change the total number, and this is an indication that the giraffe is more closely related to humans than to dinosaurs. In fact, our ancestries diverged just 110 million or so years ago.

**Luis Villazon**

# What is Venus's atmosphere made of?

**Robert Arrington**

Venus might be named after the goddess of beauty, but in reality it's a hellish planet of scalding temperatures and crushing pressures, largely as a result of an atmosphere that's mainly made up of toxic, choking carbon dioxide. This heavy gas comprises 96.5 per cent of the Venusian atmosphere, with nitrogen accounting for most of the remaining 3.5 per cent and other gases reduced to tiny traces. Just like on Earth (where it only accounts for 0.04 per cent of the atmosphere), carbon dioxide acts as a powerful greenhouse gas, trapping heat near the surface of Venus and creating searing temperatures of around 470 degrees Celsius (880 degrees Fahrenheit). As if that wasn't bad enough, the brilliant clouds that make Venus look so beautiful are actually made of corrosive sulphuric acid!



**Giles Sparrow**

How long can a submarine stay underwater? Find out on page 84

# BRAIN DUMP

Because enquiring minds want to know...

What is dark matter?
Find out on page 85

## Want answers?

Send us your questions using one of the methods opposite and we'll get them answered

## How long can modern submarines remain underwater without having to surface?

**William Harvill**

Thanks to their state-of-the-art, built-in reactors, modern nuclear submarines never have to surface to refuel. When the submarine goes into service, it has all the nuclear fuel (such as uranium) it will need for its projected lifetime, which can extend as long as 33 years. Just as in a nuclear powerplant on land, nuclear fission in the reactor generates heat, which produces steam, which turns a turbine, which provides electricity. The reactor makes the submarine completely self-sufficient, with enough juice to keep all the equipment running day in, day out.

Modern subs don't need to come up for air, either. Chemical processes continually remove carbon dioxide from the air on board, while oxygen generators use electrolysis to extract oxygen from surrounding seawater. As long as the equipment is working properly, the air is always fresh and breathable. Similarly, on-board distillation plants continually turn seawater into clean drinking water.

In fact, the only limiting factor for staying submerged is the food supply. Submarines typically carry about 90 days' worth of food, which is kept in storerooms, refrigerated rooms and freezers. For exceptionally long missions, when the storerooms fill up, submarine crews may have to stack canned goods along floors and passageways as well.

**Tom Harris**

As well as preying on larger bugs like bees and moths, robber flies are not averse to cannibalism

## What is the robber fly and how did it get its name?

**Adam Frank**

Robber flies comprise the family Asilidae. There are about 7,000 species and they are found on every continent except Antarctica. They are named for their extremely aggressive and indiscriminate predation. This is the 19th-century sense of a robber, as a bandit who waylays innocent travellers, rather than the modern synonym for a thief. Robber flies don't steal anything, however they will attack almost any insect, including bees and wasps, and even some spiders. They are accomplished acrobatic flyers and often catch their prey on the wing. To help with this they have very large eyes that are raised high on the head, like pop-up headlights. Once a victim is caught, they inject it with a paralysing neurotoxin that contains enzymes to digest all the internal organs.

**Luis Villazon**

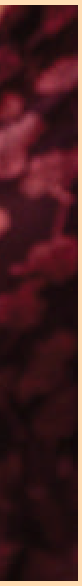
## If there's the same amount of iron in our blood as in a six-inch nail, why don't we attract magnets?

**Bill Stout**

Iron and other ferromagnetic materials (that is, ones that are naturally drawn to a magnet) are themselves made up of lots of tiny magnets. Put a chunk of iron next to a permanent magnet and these tiny magnets all line up in parallel. This allows the iron to produce its own magnetic field and attract the permanent magnet.

For this to happen, a substantial number of iron atoms need to be in close enough contact to interact with one another. Most of the four grams (0.14 ounces) or so of iron that can be found inside the average human body is bound up inside haemoglobin – the red-coloured protein in our blood which is responsible for carrying oxygen. Fortunately, as a result, the iron atoms are not concentrated enough to join forces to generate their own magnetic field and attract nearby magnets.

**Alexandra Cheung**



## Why are smoothies worse for us than just eating raw fruit?

**Helen Barnes**

■ Smoothies are hugely popular as a healthy, calorie-conscious snack that fills you up without fattening you up. But not all smoothies are created equal. The worst include ingredients like full-fat ice cream, peanut butter and chocolate, and pack over 1,000 calories – more than an entire fast-food meal. The best smoothies contain a serving of whole fruit (frozen berries, banana or even avocado, etc), low-fat dairy protein (milk, yoghurt, or non-dairy alternatives like soy or almond milk), and a natural sweetener like honey or agave nectar, which has a low glycaemic index (GI). Raw fruit is the ideal snack for a quick burst of natural energy and some extra fibre. But if you want to stave off hunger for several hours, it's best to make your own healthy smoothie from scratch at home.

**Dave Roos**

## What exactly is dark matter?

**Nicholle Aviles**

■ By measuring the motion of stars in our galaxy and others, astronomers can tell that galaxies in general contain much more mass than can be accounted for by their visible stars, gas and dust. In fact, normal, or baryonic, matter (essentially anything with protons and neutrons) seems to account for just 15 per cent of all the mass in the universe. The rest is composed of something else – something that's not just dark, but entirely transparent and unaffected by any kind of radiation. Dark matter plays an important role in the structure of the cosmos too – its enormous gravity causes baryonic matter to cluster around it, coalescing into galaxies and galaxy clusters. As a result, its distribution is similar to that of visible objects. As for what exactly it is, current research points to some kind of undiscovered heavyweight particle, capable of passing through baryonic matter as if it weren't there. Astronomers and physicists have made attempts to detect these weakly interacting massive particles (or WIMPs) and measure their properties, but so far they've eluded them.

**Giles Sparrow**

## Why does hot water wash grease away easier than cold?

**AS Fritz**

■ Washing up is less of a chore when done with hot water because heat melts fats. Heating fat makes its molecules vibrate faster and faster, weakening their bonds so that they are only loosely attached and behave like a liquid rather than a solid. Fats have fairly low melting points so a hot tap is usually enough to make them runny so they can be washed away. Bacon fat, for example, is solid at room temperature but melts at around 40 degrees Celsius (104 degrees Fahrenheit). Adding a few drops of washing-up liquid to disperse grease makes the process even more effective.

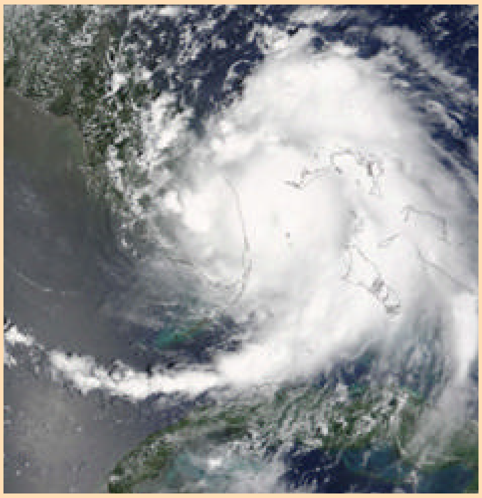
**Alexandra Cheung**

## How do stingrays eat?

**Len McNeill**

■ Stingrays, like other members of the ray family, are bottom feeders. They are related to sharks but they don't have sharp teeth. Depending on the species, they may either have two hard plates for crushing shellfish or just sucking mouthparts. Stingrays mainly eat molluscs and crustaceans, but because their eyes are right on the top of their head, they can't see their prey, so they use their sense of smell and the electric field sense common to all sharks. The venomous sting at the end of the tail isn't used to catch food – it is purely for self-defence.

**Luis Villazon**



## What brings about the eye of a storm?

**Julian Wise**

■ An eye is a characteristic feature of tropical cyclones, which are also known as hurricanes and typhoons in other parts of the world. Near the equator, warm ocean water can heat the air immediately above it, causing it to rise. As the warm, moist air rises, the air pressure below drops and surrounding cooler air rushes in. This air, in turn, heats up over the warm water and lifts as well. As the air rises, it cools, forming clouds and storms. Because of Earth's rotation, the surrounding air rushes in with a swirling motion, causing the entire storm system to spin. As it rotates faster, some air at the top of the system sinks through the centre of the storm, forming a relatively calm, low-pressure area at the heart of the cyclone: this is the eye.

**Tom Harris**

**Is bedwetting hereditary?** Find out on page 86

# BRAIN DUMP

Because enquiring minds want to know...

What makes lava glow?
Find out on page 87

## Want answers?

Send us your questions using one of the methods opposite and we'll get them answered

The Columbia Space Shuttle (pictured) tragically disintegrated on re-entry in 2003 due to damage to the heat shield

# Why was the Space Shuttle retired and what has replaced it?

**Simon Wilmott**

■ Sadly the Space Shuttle turned out to be just too dangerous – the disasters that destroyed the Challenger shuttle on launch in 1986, and the Columbia on re-entry to Earth's atmosphere in 2003, were both caused by damage to the main orbiter during launch. It turned out that the shuttle design – which strapped the orbiter to the side of its booster rockets and fuel tank – was much riskier than traditional space vehicles where crew and cargo sit in a capsule on top of the rocket stages. Since the shuttle was retired in 2011, a variety of unmanned launch vehicles have taken its place for satellite launches, while Russian Soyuz spacecraft take crews to and from the ISS. NASA is currently investigating three possible long-term replacements for manned spaceflights.

**Giles Sparrow**

# How do painkillers 'know' where to take away pain?

**Nico**

■ Most pain is caused by damage to the body's cells, communicated by specialised nerve cells called nociceptors, which run between the spinal cord and skin, muscles, some internal organs and our teeth. When something is distressing your body enough that it may damage your cells, nociceptors send an electrical message to your brain that you experience as pain.

Typically, nociceptors only fire when sensations reach a high threshold. When cells in your body are damaged, they can lower this threshold by releasing tuning chemicals. Ibuprofen or aspirin stop the production of one class of tuning chemicals, called prostaglandins. This keeps the nociceptor firing threshold higher to minimise the pain we experience. The blocking chemical enters your bloodstream, which carries it throughout your body. So, painkillers don't 'know' – they go everywhere, reaching the damaged cells in the process.

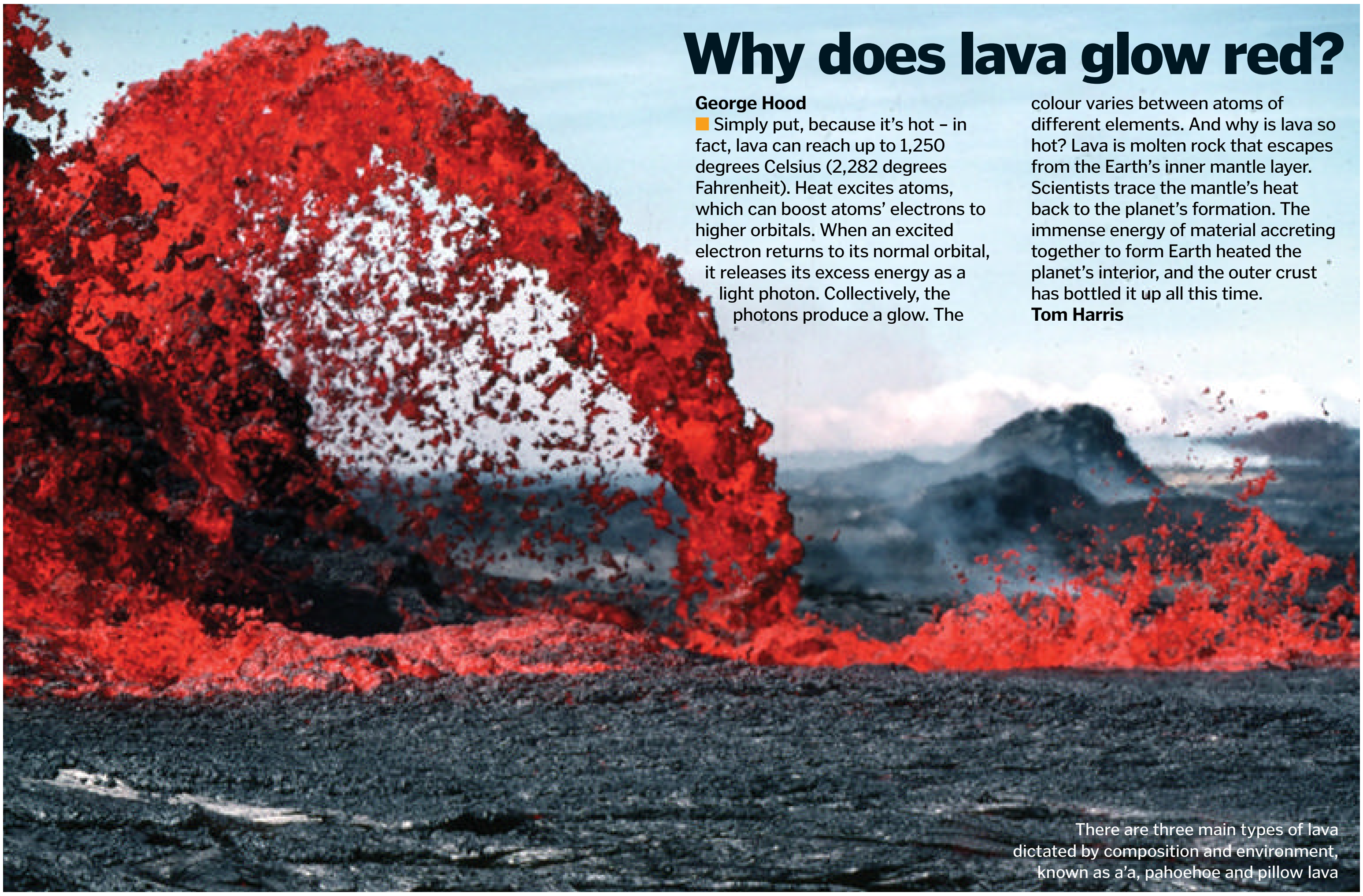
**Tom Harris**

# Why do we tend to wet the bed at a young age?

**Tyron Tsang**

■ Bedwetting, or nocturnal enuresis, is a very common childhood condition that can sometimes linger into the teenage years. Doctors estimate that 13 per cent of six-year-olds wet the bed, reducing to five per cent of ten-year-olds. There is no single cause of bedwetting, but it seems to run in the family. Bedwetters are heavy sleepers whose brains are less sensitive to the sensation of a full bladder. Most kids grow out of bedwetting naturally as their brain and bodies develop better bladder control. There is currently no 'cure' other than patience.

**Dave Roos**



# Why does lava glow red?

**George Hood**

Simply put, because it's hot – in fact, lava can reach up to 1,250 degrees Celsius (2,282 degrees Fahrenheit). Heat excites atoms, which can boost atoms' electrons to higher orbitals. When an excited electron returns to its normal orbital, it releases its excess energy as a light photon. Collectively, the photons produce a glow. The colour varies between atoms of different elements. And why is lava so hot? Lava is molten rock that escapes from the Earth's inner mantle layer. Scientists trace the mantle's heat back to the planet's formation. The immense energy of material accreting together to form Earth heated the planet's interior, and the outer crust has bottled it up all this time.
**Tom Harris**

There are three main types of lava dictated by composition and environment, known as a'a, pahoehoe and pillow lava

# How do we use ultrasound to scan for oil?

**Jennifer Cross**

When oil companies hunt for 'black gold', what they are really looking for is underground rock formations hinting at the presence of oil. One common method is to fire sound waves (lower frequencies than ultrasound) into the ground. When these waves encounter the interface between two layers of rock, they either keep going deeper or bounce back like echoes depending on the type of rock. Microphones record the resulting pattern, allowing geophysicists to build up a picture of the rocks underground. Ultrasound doesn't penetrate the rock deeply enough to do this, but it is often used to image borehole walls later on.
**Alexandra Cheung**

# Are bison extinct?

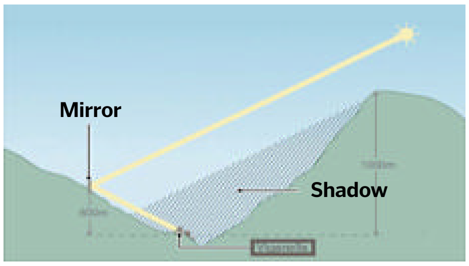
**Liz N**

No. In fact, the American Plains bison isn't even listed as endangered any more. It was a close-run thing though. In the 19th century, bison were systematically hunted for their skins. The rest of the carcass was just left to rot on the ground, where it lay. In the 1870s, anywhere between 2,000 and 100,000 bison were killed every day. At one point, the entire species numbered just 541 individuals. The bison was saved from extinction by ranchers who rounded up the few remaining animals and began to breed them. Bison have also been cross-bred with cattle to help retain enough genetic diversity. Although they are different species, bison can readily interbreed with other bovines, however the male offspring are usually sterile.
**Luis Villazon**

# Does the village of Viganella get any sunlight?

**Laura Cottingham**

Viganella does receive sunlight, but not for a few months in winter. Tucked away at the bottom of an alpine valley, this northern Italian village has a high mountain directly to the south, so that for 83 days of the year around midwinter, when the Sun is at its lowest in the sky, it never makes it above the southern horizon at all. In 2006, the local council built a large computer-controlled mirror, or heliostat, on the north slope of the valley, in an area that gets year-round sunlight. Rotating throughout the day, this reflector bounces light down into the town square, bringing some cheer to bleak winter days.
**Giles Sparrow**



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# THE KNOWLEDGE

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## Can We Travel Through Time?

**Price:** £8.99/$N/A
**Get it from:** www.quercusbooks.co.uk

Einstein once said that if you can't explain it simply, you don't understand it well enough. Well then, author Michael Brooks, you've explained the '20 big questions of physics' well enough, so we suppose that means you've definitely earned that PhD in quantum physics. In this paperback book, Brooks clearly and concisely encapsulates some of the more interesting conundrums that those not in the know might want to ask those who ought to know. Like what is the point of physics and how do we perceive time? It's an interesting read for people from all walks of life and maybe if this book had been around during the mid-Nineties void between Carl Sagan and Brian Cox, a lot of people we know might have been inspired to try a bit harder in their science lessons.

HOW IT WORKS

### Measuring time

The striatum is a small part of our brain that gives us the perception of the passage of time. Memories, drugs and even darkness can all affect the striatum and alter this perception.

Can We Travel Through Time?
The 20 BIG
HOW IT WORKS EDITOR'S CHOICE AWARD
Dust Rider
Revell

## Dust Rider Buggy RC car

**Price:** £69.99/$N/A
**Find out more:** www.revellutions.de

The Dust Rider radio-controlled buggy has several things in common with an F1 racing car. For one, it's ridiculously fast, driven by a super-light yet powerful, rechargeable lithium-polymer battery. Gently squeeze the pressure-sensitive trigger on the radio controller to ease it into acceleration, or flick it back for braking and reverse. Secondly, running the Dust Rider continuously at top speed will drain the power fast, requiring a pitstop for a recharge after around 30 minutes. Finally, its lightweight build and impressive speed mean the Dust Rider does break rather easily when accidentally ploughed into a wall (as we discovered). The modular build, however, means it's generally repairable and it does have a low gear setting specifically for indoor use if you want to avoid collisions. The Dust Rider Buggy can be purchased from **www.amazon.co.uk** in the UK.

HOW IT WORKS

### Stay in control

The Dust Rider controller transmits via a 2.4GHz frequency for a higher degree of control.

## Wii U

**Price:** From £249.99/$299.99
**Get it from:** www.nintendo.co.uk
Nintendo has been first among the console manufacturers to launch its 'next-gen' console almost consistently for the last 30 years; the Wii U continues that trend. While it's highly unlikely to be the most powerful of the three eighth-generation consoles in contention (Microsoft and Sony are yet to reveal the exact specifications of theirs), Nintendo does have a few aces up its sleeve. The Wii U finally catches up with the pack with an HDMI output and more competitive hardware for better-looking games, plus internal storage and a bay for a removable drive. The sensor bar makes a return from the old Wii along with the Wii Remote, which is compatible, but that's not the show-stopping new feature. The Wii U GamePad effectively gives the player another perspective of the game world, mapping interactive inventories, maps and more to its touchscreen interface. It can also act as a separate controller for other players and can even be used to play games when the console has been switched to standby. Its first-party launch software is heavily social network-orientated too, making this one of the most multiplayer-friendly consoles we've seen.

**HOW IT WORKS**

### Motion control

Like most of today's portable devices, the Wii U makes use of gyroscopes, magnets and accelerometers to detect tilt, rotation and acceleration in the new Wii GamePad.

## Toshiba Satellite P845t-101

**Price:** £749/$TBC
**Get it from:** www.toshiba.co.uk
People are often quite resistant to change, especially when they're more than comfortable with an operating system that already does a perfectly decent job. For the average user, the only significant difference to their OS experience when they upgrade from Windows 7 to 8 is the new tablet interface, which includes touchscreen. This is the main feature of Toshiba's Satellite P845t-101: its 35.6-centimetre (14-inch) touch display. With interface options now including keyboard, mouse, touchpad, touchscreen navigation and even touchscreen keyboard, all the bases are well covered. The P845t houses the ever-popular i5 processor, 640 gigabytes of hard disk space, internal graphics, six gigabytes of RAM and a DVD optical drive. It has also been given a faux-aluminium finish, which is quite attractive up until the point you feel the flex in the keyboard. On the plus side, the Harman Kardon stereo speakers are about as high a level of sound quality we've heard from any laptop.

We're left with mixed feelings about this device. We're not the biggest fans of Microsoft's new operating system, but the Satellite P845t-101 is a fairly comprehensive solution for those that want similar features but need more than tablet power on the move.

**HOW IT WORKS**

### A window on Windows

An operating system (OS) such as Microsoft Windows acts as an intermediary interface between a device's hardware and software.

## Zooka Wireless Speaker Bar

**Price:** £79.99/$99.95
**Get it from:** www.c14audio.com
Back in March 2012, the Zooka Wireless Speaker Bar did rather well on Kickstarter, raising over $70,000 to smash its $25,000 goal. And now it has come to the UK. It's simply a portable speaker bar that connects to any Bluetooth device (laptop, tablet, smartphone, etc) to provide additional audio output, with a 3.5-millimetre (0.14-inch) jack as an alternative input. The speaker bar is a definite step up from the standard iPhone or tablet, though a good laptop system will give it a run for its money. With eight hours of battery life, it charges via USB and comes with a rubberised silicone finish to protect it against drops and knocks, which it definitely needs as this thing is quite a lump of speaker for its size.

**HOW IT WORKS**

### What is AD2P?

This Bluetooth profile allows wireless transmission of stereo audio from an AD2P transmitter to an AD2P receiver: typically from a laptop to speakers.

# APPS OF THE MONTH

Brought to you by **Apps Magazine**, your essential guide to the best iPhone and iPad apps available on the Apple App Store

HOW IT WORKS EDITOR'S CHOICE AWARD

## iPad: War Horse Interactive Edition

**Price:** £4.99/$6.99
**Developer:** Touch Press
**Version:** 1.0.2
**Size:** 1.21GB
**Rated:** 4+
You may have seen the Oscar-nominated Steven Spielberg movie, or perhaps the impressive West End show, but before anything else *War Horse* was a beloved children's story. Here you can read the original story of a young horse recruited into the cavalry during WWI, with impressive illustrations and an audio reading from author Michael Morpurgo. There's also an 80-minute film of Morpurgo reading the novel to an audience with a folk band, plus plenty of educational content like timelines, maps and videos.

**Verdict:** ★★★★★

## iPhone: Timehop

**Price:** Free
**Developer:** Doubledub Inc
**Version:** 1.2.2 **Size:** 8.6MB
**Rated:** 4+
Ever wanted to relive treasured memories all over again? Like a social network time machine, Timehop hooks into your Twitter, Facebook, Foursquare, Flickr – and even your device's Camera Roll – so you can take a trip down memory lane. Set in a stylish UI, the app reveals the date of each shot and, oddly, the temperature.
**Verdict:** ★★★★☆

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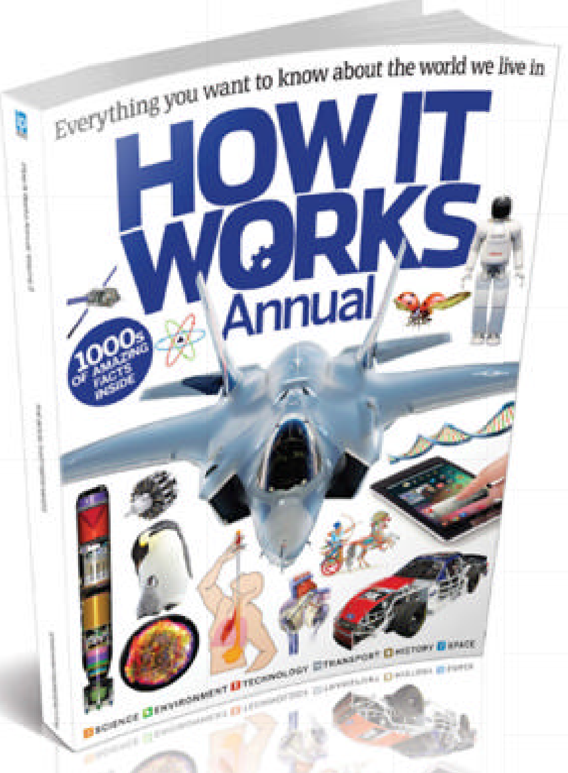

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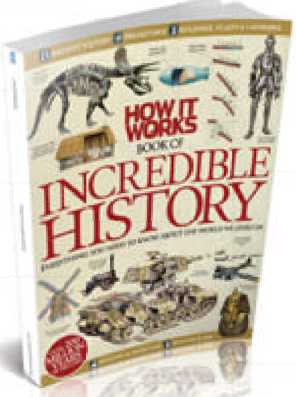

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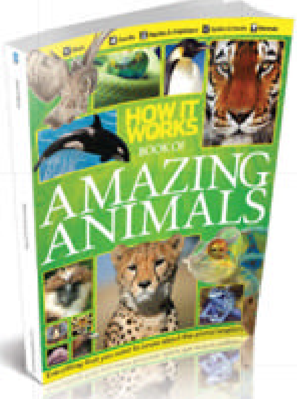

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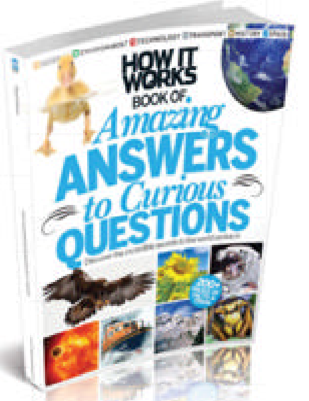

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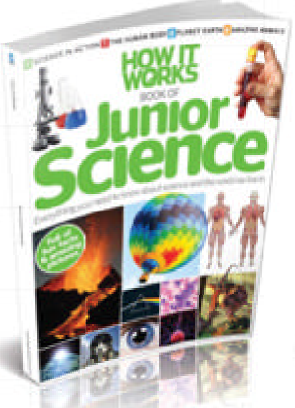

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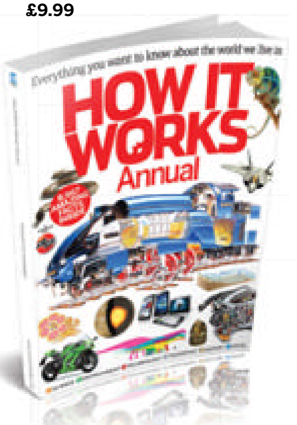

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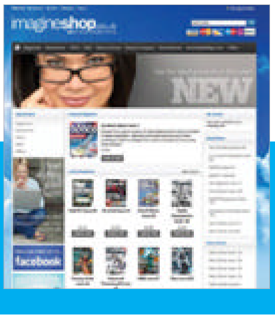

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# Gaming headsets

We pit three of the latest multi-format gaming headsets against one another

HOW IT WORKS EDITOR'S CHOICE AWARD ★★★★★

**PROS**
✓ Stylish; great sound
**CONS**
✗ Not the best value

**PROS**
✓ Superb audio; full-featured
**CONS**
✗ A bit ugly

**PROS**
✓ Very comfy to wear
**CONS**
✗ Average audio; flimsy

## Mad Catz Tritton Pro+

**Price:** £149.99/$199.99
**Get it from:** www.trittonaudio.com

True 5.1 surround sound! But what exactly does that mean? The Mad Catz Tritton Pro+'s big feature is eight sound drivers – four in each earcup – acting like separate speakers in a satellite system to replicate 5.1 surround sound. Other features include advanced speaker separation, which is vital to online gaming where sound precision can mean the difference between winning and losing, as well as selectable voice monitoring, which allows the user to choose whether they hear their own voice. It's dead sexy on paper, it looks and feels every inch a £150 set of gaming headphones and, to us, it sounds like we've just put a hefty subwoofer and four speakers in our brain. However there's a ridiculous amount of cable – at least twice as much as there should be – and this resulted in a bit of confusion during setup. As much as we enjoyed the 5.1 surround sound, there's no marked difference between this and a significantly less expensive solution, making the Tritton Pro+ more of an aesthetic upgrade than a technological leap.

**Verdict:** ★★★☆☆

## Medusa NX 5.1 Surround Console

**Price:** £149.99/$TBC
**Get it from:** www.speedlink.com

The Medusa NX 5.1 Surround Console Gaming Headset comprises similar hardware to the Tritton Pro+. Each cup houses four individual drivers that use Dolby Digital and Pro Logic II tech to deliver a 'true' 5.1 surround-sound experience. The difference is that real surround sound – whether piped through a sub and satellite speakers or via a gaming headset – is noticeably more realistic. The Medusa NX had us swivelling in our seat to pinpoint arbitrary noises that were apparently coming from somewhere in our living room. This headset is furnished with a surprising number of other features too. In addition to standard analogue and digital inputs, separate chat and game volume levels and noise-reduced mic boom, the Medusa NX 5.1 boasts parallel headset and speaker use and a collapsible design which allows the cups to fold away for easy transport. It may lack a bit in style, but it more than makes up for this in substance.

**Verdict:** ★★★★★

## Sennheiser U 320

**Price:** £109.99/$169.95
**Get it from:** www.sennheiser.com

Sennheiser's U 320 multi-platform gaming headset offers a sort of middleground between gaming peripheral and stereo headset. On the one hand, it's plug and play compatible across all gaming formats (except Nintendo), with RCA, 2.5-millimetre (0.1-inch) Xbox controller jack and USB plugs, plus a mic boom with game and chat volume control. On the other hand, it's a very comfy stereo audio experience – something more synonymous with the commuter's world of music players and portable DVD players. Digital surround is rapidly becoming the norm for gaming headsets, so Sennheiser has incorporated a bass boost to give explosions and rumbling engines a bit of a kick. Hardly a competitor for quality surround, but as long as your game doesn't take you into the competitive realms of professional gaming, it probably won't take the edge off your performance even if you do miss one or two background noises. They're undeniably comfortable, but the build quality left us wanting, with a frightening amount of flex in places.

**Verdict:** ★★☆☆☆

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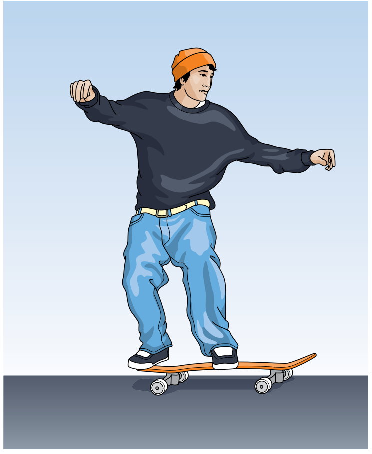
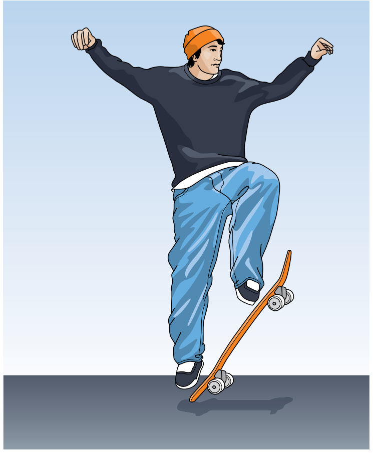
# Execute an ollie

By analysing the science of skateboarding, you'll be on a roll in no time…



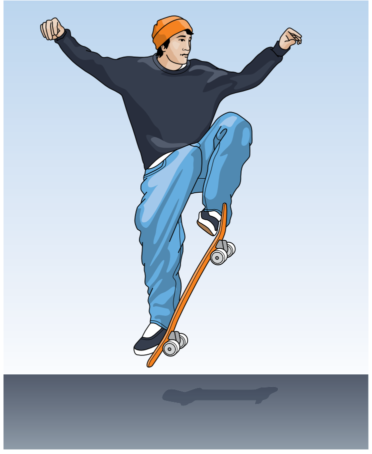
### 1 Basic forces

Due to factors like the skater's position and their physical build, a rider possesses a certain amount of potential energy. This can be converted into kinetic energy to overcome gravity and friction, granting momentum. For tricks that involve spins and/or twists, part of this kinetic energy will transform into rotational energy. Velocity can be built by peddling against the skate surface, or by the rider lowering and then rapidly raising their centre of mass (ie crouching and then standing).



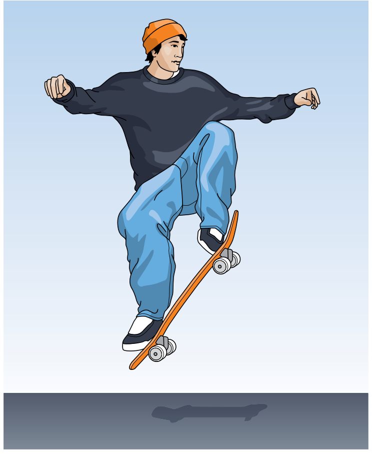
### 2 Generating air

The main technique used to get off the ground, without the feet leaving the board, is called an 'ollie'. To do this the skater again crouches to reduce their centre of mass before quickly accelerating by standing rapidly. As they straighten, the rear foot presses hard on the back of the board, so it pivots counterclockwise about the rear axle and hits the ground. As dictated by Newton's third law of motion, the reactive opposite force pushes both board and skater into the air, overcoming gravity.



### 3 The right balance

Now airborne, the skater needs to address an imbalance in board angle and their own centre of mass in order to stay in control. This involves the rider smoothly sliding their forward foot up the board, exploiting the friction between their sole and the board's rough surface. This repositions the skater over the board without removing their feet from it, allowing their centre of mass to shift back towards the centre so they can ready themselves to draw the board parallel to the ground.



### 4 On a level

For the board to become parallel with the skate surface once more, the skater needs to push their front foot down on the board, raising the rear so that it's on a level, while at the same time moving their rear leg towards the middle. These things need to be done in unison, and in a controlled manner, as if the boarder's centre of mass shifts too far forward, they are likely to overcompensate, resulting in the front tip of the skateboard angling toward the ground and a potential wipeout.

# Dig a vegetable patch

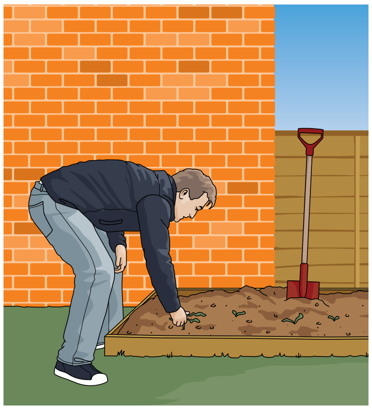
Green-fingered tips to

### 1 Prepare the plot

Soil is obviously a necessity for growing any plants, but more specifically for vegetables the earth should be slightly acidic (around 6.5 pH). While planting in normal topsoil is fine, creating a raised, enclosed bed is a good idea as the earth dries out quicker (to avoid rotting) and provides extra depth for roots. For enclosed beds, a square or rectangle of wooden beams, sleepers or logs is ideal.

### 2 Choose your veg

Once you've weeded the soil, you can decide what to grow. This depends largely on the soil quality, quantity of sunlight and size of plot. As a general rule, more compact plants – such as leeks and carrots – are best for garden plots as they require little maintenance and mature faster than more rambling crops. Also you need to decide whether to grow from seed or from more pricey plugs.



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**5 Ready to land**

The rider and board should now be parallel to the skate surface. At this point, velocity and momentum are allowing them to overcome gravity and air friction. However, they still have potential energy, which has been increased by their new, elevated position. As gravity overcomes the latter forces the skater lands safely by once more reducing their centre of mass, bending their legs and crouching. This enables them to absorb most of the upwards force generated on touchdown.

**6 Coming to a stop**

After the rider makes contact with the skate surface, friction instantly begins to reduce forward movement. As such, if no other force acts upon the skater, they will steadily be overcome by friction and gravity until they come to a complete halt. In contrast, forward momentum can be maintained – to some degree – by the rider raising their centre of mass after making contact with the ground/halfpipe, generating a small boost in speed, as we've previously seen in step 2.

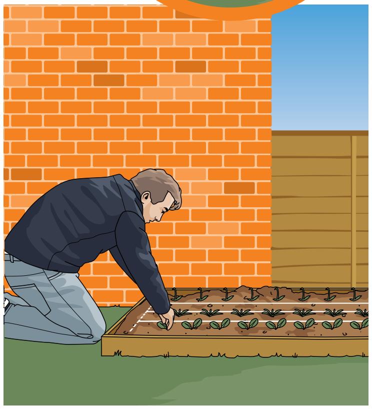
**In summary…**

Through this step-by-step, we've shown some of the core science behind skateboarding. For both jumping and landing, a low centre of mass (ie crouched position) is a must for better handling the forces at play. In addition, vertical acceleration of the body at the start of an inclined plane can increase speed, making it easier to generate big air on a halfpipe. Finally, the position of a boarder within any local environment hugely affects their potential energy, which determines the total velocity and momentum they can achieve.

## create a tasty veg garden

**3 Get planting**

You can plant directly into the soil, but for town gardens, add some organic fertiliser. Create a series of rows, leaving as much room as possible to avoid crowding. As a rough guide, salad rows should be separated by 20 centimetres (eight inches) and carrots 35 centimetres (14 inches). Poke a small hole, insert the seed/seedling, cover with a handful of soil and sprinkle with water.



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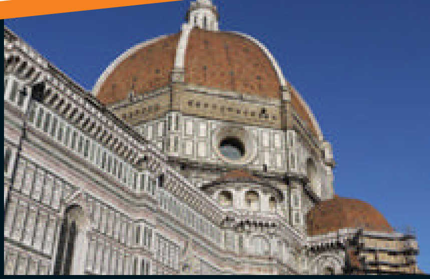
NEXT ISSUE
- Use chopsticks
- Sail a boat

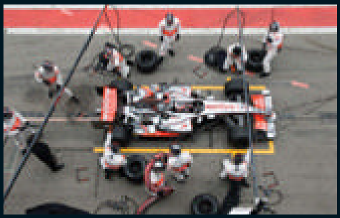
# TEST YOUR KNOWLEDGE

ENJOYED THIS ISSUE? WELL, WHY NOT TEST YOUR WELL-FED MIND WITH THIS QUICK QUIZ BASED ON THIS MONTH'S CONTENT?



1 How fast did the X-43 jet go when tested in 2004 (mph)?
A:

2 Which car was fitted with a keyless entry system first?
A:



3 What is the record for a four-wheel tyre change in F1?
A:

4 During which epoch were most estuaries created?
A:

5 What is the boiling point of the noble gas helium?
A:

6 How many years did it take to build the Duomo's dome?
A:

7 Who performed the first-ever spacewalk?
A:

8 What size screen does the Wii U's GamePad have (cm)?
A:

9 In what position did George Armstrong Custer graduate from his class at West Point Military Academy?
A:

10 How long ago did the Brachiosaurus live?
A:

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**> ISSUE 42 ANSWERS**

**1.** 1643 **2.** $300,000 **3.** 6.7l V6 **4.** Dione **5.** 100 tons **6.** Late Cretaceous **7.** 24 **8.** Khmer **9.** 2hrs, 36mins **10.** 5.95 seconds

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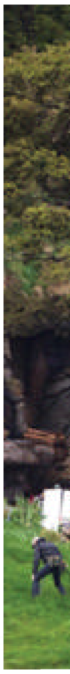

# Get in touch!

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### Letter of the Month

## Industrial revelation

**Hi HIW**

An absolutely superb introduction to the Industrial Revolution. Five full spreads, excellently illustrated with enough detail to whet the appetite of anyone even remotely interested in science history. This cover story, along with the article on 'Light and colour' and the fascinating story about the life and times of Johannes Kepler must surely attract many young readers to continue their passion for learning and continue to expand their knowledge and education in science. I think the magazine in general goes a long way to encouraging young readers to enter a career in science and I think your entire staff do a wonderful service to ensuring we will have a further generation of scientific enthusiasts. I only make it out to the UK (London) about once a year, and with each trip I try to visit interesting places of science or history. This issue [41] has added plenty of 'to-do items' for my next visit.

**Paul Bouloudas (Perth, Western Australia)**

**Thanks, Paul. This was a lovely email to be greeted with upon our return after the Christmas break. We're delighted you enjoyed the Industrial Revolution issue.**

Genetically modified crops have lots of potential but remain controversial due to unknown side effects

## I've had a totally bananas idea…

**Hello HIW,**

Was thinking this morning over breakfast that it would be cool if different fruits were spliced together to create hybrid fruit. Just have scientists take the best bits from each and inject them into, say, a banana, creating one that is twice the size and filled with enhanced nutrients from apples, mangoes, etc.

**Tom**

**Wow, Tom, that must have been quite a breakfast to come up with an idea like this! While your suggestion might at first sound fanciful, many fruit crops are already modified to enhance their resistance to disease, insect pests and water saturation.**

## Metallic monster

**Hi,**

If you combined all the metallic elements found in the periodic table would you produce a super-alloy?

**Clive**

**Hi Clive. The short answer to this is no. The reason is that the entire purpose of creating an alloy is that you are combining two or more metals to exploit one or more of their intrinsic properties. For example, alloying copper and tin creates bronze, which is harder, tougher and stronger than either of its constituent parts. Not all metals have these potentially beneficial properties. For example, iridium is incredibly brittle – a quality that for most applications would not be very useful. Essentially, alloying works best when metallic elements are chosen carefully and combined in small numbers with one aim in mind. Joining all of them together would most likely create something like 'Frankensteinium'!**

## Middle-earth in the frame

**Hey,**

With all this talk of *The Hobbit* movie being filmed at 48 frames per second [fps] and that it looks 'too real', I just don't understand why that is. Films before were shot at 24fps and surely that number was chosen for a reason – I mean, it looks fine to me! Can human eyes even see 48fps or is it another 3D-style marketing gimmick?

**Adam Barnet**

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Despite receiving mixed reviews for its novel filming methods, *The Hobbit* is the highest-grossing Christmas movie of all time

## "Joining all the metals would most likely create something like 'Frankensteinium'!"

**Let's start with your final point. Yes, human eyes can distinguish 48fps and even 60fps – hence the *Hobbit* debate. Key to this is the fact that films have always been shot at 24fps (well, for the last 80 years), which is roughly the equivalent of TV broadcasts (eg 25fps in the UK). With *The Hobbit* that frame rate is doubled, with twice as many frames per second. This gives footage a smoother, cleaner appearance and – especially when fast camera movements are made – a less blurry image. That said, some feel the 48fps footage falls into a kind of 'uncanny valley' where realism isn't achieved but neither is the traditional appearance of 24fps footage.**

## A little off centre

■ **Hi HIW,**

I bought this month's How It Works [issue 41] for the first time and I must say I am very impressed with a thought-provoking and interesting magazine. Being a geography teacher I was particularly interested in the article '25 Earth-shattering facts'. However, the very first fact in the article is wrong. The epicentre of an earthquake is located on the surface; it is the focus point underground from which the earthquake originates. So it should read: what's the deepest *focus* on record – not epicentre.

**Mr G Jones (Liverpool, UK)**

**Thank you very much for your letter, Mr Jones. You are indeed correct to point out that an earthquake's epicentre is the area on the Earth's surface that is directly above the point of the earthquake's subterranean origin – the latter commonly referred to as the hypocentre, or focus. It is at this 'ground zero' that a quake's core explosion is released, only for it to travel up to create the epicentre. We hope you continue to enjoy the mag.**

## What's happening on... Twitter?

We love to hear from **How It Works**' dedicated readers and followers, with all of your queries and comments about the magazine and the world of science, plus any topics which you would like to see explained in future issues. Here we select a few of the tweets that caught our eye over the last month.

@BrettsWifeToBe
**@HowItWorksmag**
Love the origami in the pic. Wish I could do that

@justconnectme
**@HowItWorksmag**
Always good to meet like-minded people. You definitely do need to subscribe – this mag is flippin' great :)

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Merry Christmas! Joyeux Noël!

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**@HowItWorksmag**
OMG! x

@Hellboy919
**@HowItWorksmag**
Just bought the latest edition of How It Works this morning – another jam-packed issue full of great information as ever

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**@HowItWorksmag**
Articles like this help me keep my small worries in perspective! Thanks for this well-written piece, mates!

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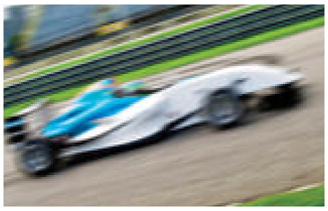

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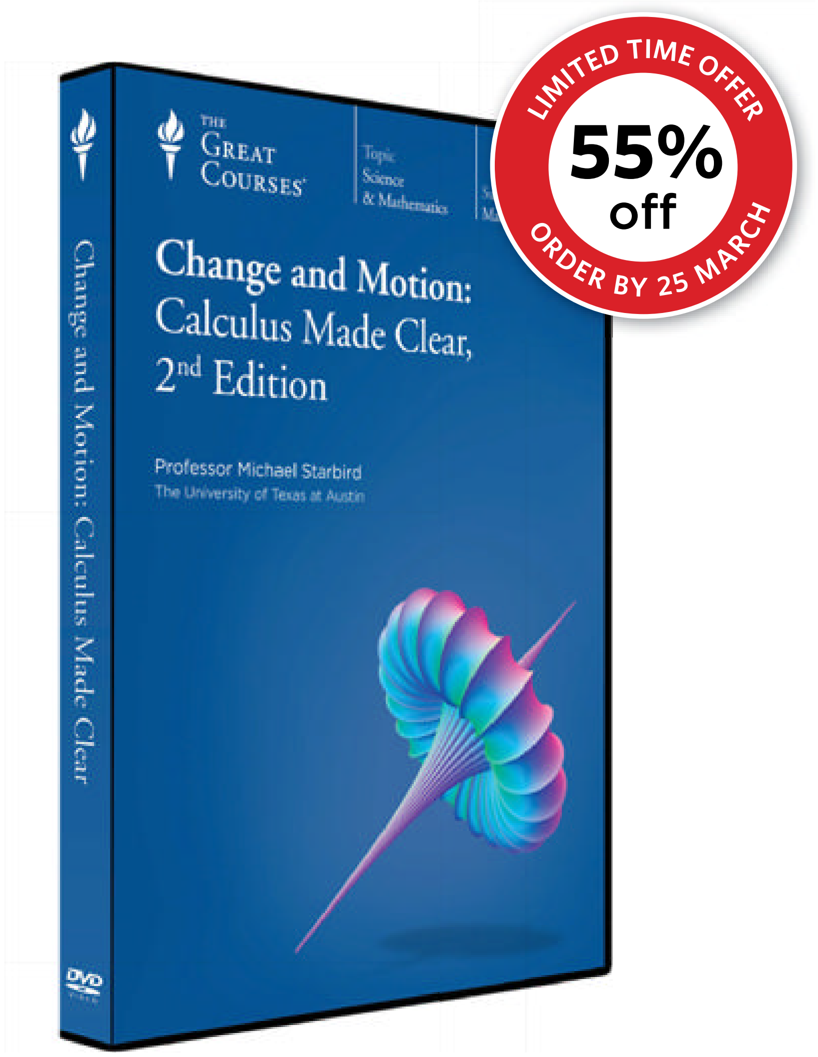
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